

THE APPLICATION OF A STATISTICAL
ANALYSIS SOFTWARE PACKAGE TO
EXPLOSIVE TESTING

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C. LAM

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The Application of a Statistical Analysis Software Package to Explosive Testing

C. Lam

MRL Technical Report
MRL-TR-93-42

Abstract

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The report describes a user-friendly software package for the analysis and presentation of results from explosive destructive testing. The analysis covers the Bruceton, Probit and Army Materiel Command Regulation (AMCR) statistical methods. The program is illustrated by its application to several small scale tests for the assessment of explosive sensitivity to various stimuli. They are the Gap test, Jet Sensitivity test, Slapper Detonator test and Cap Sensitivity test.

The report includes an overview of the basis of the mathematical equations used in the evaluation of the statistical data, and the menu commands in the computer model are described.

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The Application of a Statistical Analysis Software Package to Explosive Testing

1. Introduction

Many ordnance evaluations involve the study of reliability and safe functioning of an energetic material or device. This calls for statistical analysis methods to accurately evaluate a given set of data. For explosive testing purposes, Material Research Laboratory (MRL) uses three methods to carry out the analysis; these are Bruceton, Probit and Army Materiel Command Regulation (AMCR).

Much of the evaluation of high explosive sensitivity, fuse tests, etc. is based on collecting a set of data that is obtained at various levels for a given test condition. The results of the individual tests are recorded as 'detonation, non-detonation' or 'fire, no-fire'. Reducing the output from the tests to a simple 'go, no-go' criterion allows the data to be analysed statistically by the models cited above. These three models are widely used at MRL for the assessment of material and component sensitivity. Manually performing these calculations, is time consuming and prone to human errors, thus producing misleading results. For these reasons, a user-friendly computer model was developed and validated against several sensitivity tests. The report describes the software and its application to four types of explosive sensitivity tests.

2. Description of Equations Used in the Statistical Analysis

The equations described below are the basis of the computer model used to undertake the statistical evaluation of a given set of data. All equations and conditional-trees have been programmed and reference graphs digitised, so no manual calculations are required.

2.1 Bruceton Method

The basis of the Bruceton Analysis method used in the program is extracted from Dixon and Mood [1]. Assuming that the data under analysis is normally distributed, this method provides a good estimate of the mean (m); at the mean there is an equal chance that the charge will detonate or non-detonate. The spacing (d) between the test levels in the Up-Down scheme must be constant and, ideally, the analysis requires a large sample size, say at least fifty, to avoid misleading results. However, in practice, due to experimental time and

cost constraints testing may involve as few as ten shots although twenty to twenty-five shots is common. The following expressions are the basis of the program's computations.

A. Calculation of the mean estimate (m).

$$m = c + d \left[\frac{\sum i n_i}{\sum n_i} \pm 0.5 \right] \quad (1)$$

where,

- c , is the lowest level used in Bruceton Analysis
- d , is the constant step interval between levels
- i , is a number given to each test level starting with zero
- $\sum n_i$, represents the smallest total number of detonations or non-detonations
- \pm depending on the stepping method, a plus or minus sign is used.

A decision to use either the plus or the minus sign in equation (1) is based on the following;

In a "Increment when Detonate" stepping method, if the detonations are the smaller of the two, apply the plus sign to the equation or conversely, the minus sign is used when analysis is based on non-detonations.

In a "Decrement when Detonate" situation, apply the minus sign to the equation when analysis is based on detonations, otherwise, use the plus sign when non-detonations are taken for the calculation.

The mean and standard deviation are estimated either from the detonations or the non-detonations, whichever is the smaller.

B. Calculation of the standard deviation estimate (s).

(i) compute the value of M ,

$$M = \left[\frac{\sum i^2 n_i}{\sum n_i} \right] - \left[\frac{\sum i n_i}{\sum n_i} \right]^2 \quad (2)$$

(ii) M is then used to find the value of s from Appendix II Graph I and II,

if $M > 0.3$ then, use the following identity

$$s = 1.62(M + 0.029), \text{ which is an estimate for Graph I} \quad (3)$$

if $M \leq 0.3$ then

s is read directly from Graph II, which has been digitised and incorporated into the program.

If M falls below 0.3, the curve that is closest to $diff$ (eq. 3a) is chosen and the value of s is read straight from the curve with respect to the M value. The interpolation method (eq. 3b) is applied if the calculated M value lies between two digitised M values, giving a more accurate value of s .

In deciding which curve on Graph II to use to obtain a value for s , the following procedure is performed. This is based on the equation;

$$diff = \frac{c_{nearest} - m}{d} \quad (3a)$$

where, $c_{nearest}$ is the nearest test level to m and $diff$ represents the distance between the mean and the nearest level to the mean. If $diff$ lies on one of the four curves, the s value is read directly from that curve, otherwise, the curve that is nearest to $diff$ is chosen to obtain the value of s with respect to the value of M . This procedure is depicted below, where h is one of the testing levels.

```

if  $diff \geq 0$  and  $diff \leq 0.05$ 
    select  $m - h = 0$  curve,
else
    if  $diff > 0.05$  and  $diff \leq 0.175$ 
        select  $m - h = 0.1d$  curve,
    else
        if  $diff > 0.175$  and  $diff \leq 0.375$ 
            select  $m - h = 0.25d$  curve,
        else
            select  $m - h = 0.5d$  curve

```

Linear interpolation (eq. 3b) has been implemented in the software to interpolate between points on the closely digitised curves.

Example,

$$s = s_1 + \frac{n - n_1}{n_2 - n_1} (s_2 - s_1) \quad (3b)$$

where,

- s is the interpolated value corresponding to n
- n is the point that lie between n_1 and n_2 on an axis
- s_1, s_2 is the two points that lie on the other axis.

(iii) The standard deviation is computed as,

$$\sigma = ds \quad (4)$$

C. Calculation of the mean standard error (σ_m).

The mean (m) presented represents only the mean of the sample tested and not the mean of the whole population, subsequently, it is exposed to sampling error. To adjust for this, a standard error for m is obtained using

$$\sigma_m = \frac{\sigma G}{\sqrt{\sum n_i}} \quad (5)$$

where G factor is obtained from Appendix II Graph III and IV, with respect to the s value. Depending on the s value, the G factor is either read directly from the digitised points or from interpolation between two digitised G values. For example, if an estimated mean value lies on or half of d away from the nearest testing level, the G value is read directly from the digitised curve, otherwise, the G value is obtained by interpolating between the curves.

D. Calculation of 95% confidence limit of mean.

The 95% confidence limit represents a 0.95 probability where the true mean lies and it is a way to define the accuracy of the mean acquired.

$$L95\%(m) = m \pm t_{0.95} \left[\frac{\sum n_i + 1.2}{\sum n_i} \right] \sigma_m \quad (6)$$

where the value of $t_{0.95}$ is given by the t distribution for $\sum n_i - 1$ degrees of freedom and

$\left[\frac{\sum n_i + 1.2}{\sum n_i} \right]$ is a correction factor which is ineffective when large sample size are used.

2.2 Probit Method

The basis of the equations implemented in the software is originated from Finney [2]. Transformation of percentages to probit is the basis of this statistical analysis method. It assumes that data samples are either normal or log-normal distribution. The method is capable of being adapted to data of unequal sizes at each test level and the difference between these levels need not be equally spaced.

For a given percentage, the probit (Y) may be defined as

$$Y = 5.0 + \left[\frac{x - \mu_p}{\sigma_p} \right] \quad (7)$$

where,

x is the test level, ie. voltage level for cap sensitivity test

μ_p is the mean of the population

σ_p is the standard deviation of the population

The second part of equation (7), $\left[\frac{x - \mu_p}{\sigma_p} \right]$, represents the percentage of the area under the normal distribution curve for various x values and is commonly written as $\alpha_p + \beta_p x$, where

$\mu = -\frac{\alpha_p}{\beta_p}$ and $\beta = \frac{1}{\sigma_p}$; subscript 'p' denotes the population.

A. Calculation of the Empirical Probit.

The transformation of observed percentages to probit is designated as Empirical Probit. Using Abramowitz and Stegun [3], which approximates the inverse of the normal distribution function, the following applies;

$$p = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^y e^{-\frac{y^2}{2}} dy \quad (8)$$

$$\text{where, } y = \left[\frac{x - \mu_p}{\sigma_p} \right] \quad (8a)$$

Approximation of the function from Abramowitz and Stegun [3, eq. 26.2.23] is derived as,

$$ep = t - \left[\frac{c_0 + c_1 t + c_2 t^2}{1 + d_0 t + d_1 t^2 + d_2 t^3} \right] \quad (9)$$

where,

$$t = \sqrt{-2 \ln \left(\frac{1}{2} - \left| \% - \frac{1}{2} \right| \right)}$$

%	observed percentage at each test level
c_0	2.515517
c_1	0.802853
c_2	0.010328
d_0	1.432788
d_1	0.189269
d_2	0.001308

Therefore, $Y = 5.0 + -ep$, when $0 < \% \leq 0.5$
 $Y = 5.0 + ep$, when $0.5 < \% < 1.0$

B. Calculation of the Provisional Probit.

The provisional line provides a means of estimating the level at which a specified Expected Probit occurs. The equation for the provisional line is computed using,

$$Y = 5.0 + y' \quad (10)$$

where, $y' = \beta(x - \mu)$;

and, $\beta = \frac{1}{\sigma}$; is the slope of the provisional line

μ is the sample mean estimate

σ is the sample standard deviation estimate

C. Calculation of the Expected Probit.

The Expected Probit for each empirical percentage versus its Provisional Probit is computed as

$$Y = 5.0 + y'' \quad (11)$$

$$\text{where, } y'' = y' + \frac{\% - p}{z_y}$$

% observed percentage

p is defined in equation (17)

z_y is defined in equation (19)

D. Calculation of the threshold statistics for a given percentage ($\bar{x}_{\%}$).

The mean of the no-fire level is calculated using equation (12), and is originated from equation (8a). The value for ep is derived with equation (9), which is equivalent to the no-fire probability.

$$\bar{x}_{\%} = \mu + ep\sigma \quad (12)$$

E. Calculation for the threshold standard error for a given percentage (σ_m).

This is given by,

$$\sigma_m = \frac{1}{\beta} \sqrt{\frac{1}{\sum w_f} + \frac{(\bar{x}_{\%} - \bar{x})^2}{S_{xx}}} \quad (13)$$

where w_f is the weight factor as in equation (16); $n_i w_c$

\bar{x} is defined in equation (20); weighted mean of x

S_{xx} is expressed in equation (22)

F. Calculation of the 95% confidence limit of the threshold ($x_{95\%}$).

The 95% confidence limit of the no-fire percentage threshold is calculated using,

$$x_{95\%} = \bar{x}_{\%} - t_{0.95} \sigma_m \quad (14)$$

Assuming large sample theory, the value of $t_{0.95}$ from the t distribution table is equal to 1.645. For the 95 percent confidence limit of the fire threshold, replace equation 14 with a plus sign.

2.2.1 Computational Procedures.

1. The Empirical Probit for each test level with respect to the no-fire percentage is calculated using equation (9).
2. The Provisional Probit, the Expected Probit together with the no-fire threshold, the variance and the 95% confidence limit are calculated as follows,
 - 2.1 get current estimates (μ, σ),
 - 2.2 calculate Provisional Probit using equation (10),
 - 2.3 evaluate for the weight coefficient (w_c) and weight factor (w_f) for each Provisional Probit value as follows,

$$w_c = \frac{z_y^2}{pq} \quad (15)$$

$$w_f = n_t w_c \quad (16)$$

where, $q = 1 - p$, and n_t is the total number of shot at each level

The value of p in equation (15) is derived as,

$$\begin{aligned} \text{if } y < 0, \quad \text{then } p = f \\ \text{if } y \geq 0, \quad \text{then } p = 1 - f \end{aligned} \quad (17)$$

where, f is the Normal Probability Density Function, and is defined as

$$f = z_y [a_0 h + a_1 h^2 + a_2 h^3] \quad \text{in A&S[3, eq. 26.2.16]} \quad (18)$$

where,

$$a = 0.33267$$

$$a_0 = 0.4361836$$

$$a_1 = -0.1201676$$

$$a_2 = 0.937298$$

$$h = \frac{1}{1 + a|y|}$$

$$z_y = \frac{1}{\sqrt{2\pi}} e^{-\frac{y^2}{2}} \quad (19)$$

2.4 the Expected Probit for each empirical percentage versus its Provisional Probit is evaluated using equation (11).

2.5 compute for probit line and the sum of squares and products about the mean,

$$\bar{x} = \frac{\sum w_f x}{\sum w_f} ; \text{ weighted mean of } x \quad (20)$$

$$\bar{y} = \frac{\sum w_f y''}{\sum w_f} ; \text{weighted mean of } y \quad (21)$$

$$Sxx = \sum w_f x^2 - \frac{(\sum w_f x)^2}{\sum w_f} \quad (22)$$

$$Sxy = \sum w_f xy'' - \frac{\sum w_f x \sum w_f y''}{\sum w_f} \quad (23)$$

$$Syy = \sum w_f y''^2 - \frac{(\sum w_f y'')^2}{\sum w_f} \quad (24)$$

2.6 calculation for the new estimate (μ, σ) and chi-square,

$$\sigma = \frac{1}{\beta} = \frac{S_{xx}}{S_{xy}} \quad (25)$$

$$\mu = \bar{x} - \sigma \bar{y} \quad (26)$$

$$\text{chi-square} = S_{yy} - \frac{(S_{xy})^2}{S_{xx}} \quad (27)$$

3. Repeat procedure 2.1 to 2.6 until the probit line is an approximation that results in convergence. In the program, convergence is reached when current *chi-square* minus previous *chi-square* is less than 0.0003.

4. Finally, the desired no-fire probability percentage (%) is subjected to equation (12), (13) and (14) to obtain the necessary no-fire threshold ($\bar{x}\%$), the standard deviation (σ_m) and the 95% confidence limit ($x95\%$) for the threshold statistics.

2.3 Army Materiel Command Regulation (AMCR) Method

Army Materiel Command Regulation (AMCR) [4] is a simple, fast method and capable of handling large data at each test level. Like Bruceton, the step interval between test levels must be equally spaced. Within these test levels, it must have one level having all its results going one way and another going the other way, ie. 100% no-fires and 100% fires. The equations below are the basis of the method used in the software.

A. Calculation of the mean estimate (m).

This is given by,

$$m = \sum P_i d + \left[H100\% + \frac{d}{2} \right] \quad (28)$$

where,

$\sum P_i$ is the sum of the no-fire percentage at each level

d represents the step interval between levels

$H100\%$ is the first test level that all sample misfire

B. Calculation of the Standard Deviation (σ).

This is given by,

$$\sigma = \sigma' m \quad (29)$$

where,

$$\sigma' = \sqrt{\sum k_i P_i - \sum P_i^2}; \quad (30)$$

is the standard deviation uncorrected for the test interval

$\sum k_i P_i$ is the sum of the variance factor k_i multiplied by the no-fire percentage (P_i) at that

level. At the all no-fires test level, $k_i=1$ and $k_i=k_i+2$ for subsequent levels, ie. $k=1,3,5,7,\dots$

$\sum P_i$ is the sum of the no-fire percentage at the current level.

2.4 Choice of Method

The three methods described above provide a means of estimating and evaluating data. However, one may be better suited for a particular set of data than another. Here are a few points which might be helpful in deciding which method to apply;

(i) Bruceton Analysis :

- concentrates very much on the mean, hence provides more accurate estimate about the mean. But it is not a good method for estimating small or large percentage points [1].
- at least fifty data points[1].
- requires fewer tests for a given accuracy[1].
- the 95% confidence limit is implemented.
- necessary to have constant spacing between test levels; software restriction.
- maximum number of data points is two hundred, but expandable; software restriction.

(ii) Probit Analysis:

- does not require constant spacing between test levels [2].
- many data points at each test level is possible.
- maximum thirty test levels, but expandable; software restriction.
- the 95% confidence limit is implemented.
- can not utilise the all fires and all no-fires levels. Fisher and Yates (1964, Table IX).

(iii) AMCR Analysis:

- constant spacing between test levels is necessary [4].
- thirty test levels maximum, but expandable; software restriction.
- quick and easy way to approximate results.
- provides estimate of the mean and standard deviation only [4].
- has no 95% confidence limit.
- requires the all fires and all no-fires levels [4].

3. Description of the Statistical Analysis Software

3.1 Software and Hardware Requirements

The recommended computer system should include :

- IBM AT or compatible Personal Computer
- IBM colour VGA graphics card or any other card compatible with Microsoft Windows, version 3.0 or higher
- IBM colour monitor or compatible. Under Windows environment it should be running at VGA mode (640 x 480 pixel)
- at least 2 megabytes of Random Access Memory
- Hard disk with at least 1 megabyte available
- Microsoft mouse or any other pointing device compatible with Microsoft Windows 3.0 or higher
- HP LaserJet II printer or higher or any other compatible LaserJet printer

With Operating System (PC or MS-DOS 3.0) and Microsoft Windows version 3.0 or 3.1 installed on the computer system, the software package requires two more files; the executable file (stwin93.exe) and Borland's Dynamically Linked Library file (bwcc.dll).

3.2 General Development Details

The three methods of statistical data analysis (Bruceton, Probit & AMCR) were converted into a user-friendly computer program. Two versions of the program were developed; a DOS version and a Windows version. However, the following descriptions apply to the Windows version only. The Windows version of the program is very easy to use. It has been written to the Windows standards, meaning that the users deal with the same screens, menus and methods regardless of the application they're working in, thus reducing the learning curve and boosting productivity.

The application program was developed under Microsoft Windows version 3.0 environment using Borland C++ version 3.1 software development tools. During the development phase, the program was compiled and run on a 486 computer system with a super VGA monitor running at 640 x 480 pixel as well as eight megabytes of Random Access Memory. The Output device used was a HP LaserJet III printer. Of course, this is not the minimum criterion. Refer to section 3.1 for software and hardware requirements.

The computer model requires two files to run, the executable file (stwin93.exe) and Borland's Dynamically Linked Library file (bwcc.dll). During the development of the application software, interaction with operators enabled the refinement of the software, for example, having the up-down graph or ratio bar graph helps to make the raw data more readable. The program has been tested and is now being used in various analyses at MRL.

3.3 Application Software Menu Descriptions

When the statistical analysis software is loaded, the main application window will appear on the screen, as shown in Figure 1. The program's main menu bar has four menu items (File, Method, Misc., and Help) that are available to the operator. Each menu item contains more sub-menu items to perform a specific task. This is depicted in Figure 2 and an explanation of each menu command is described below. The structured diagrams of the program can be referred to in Appendix I.

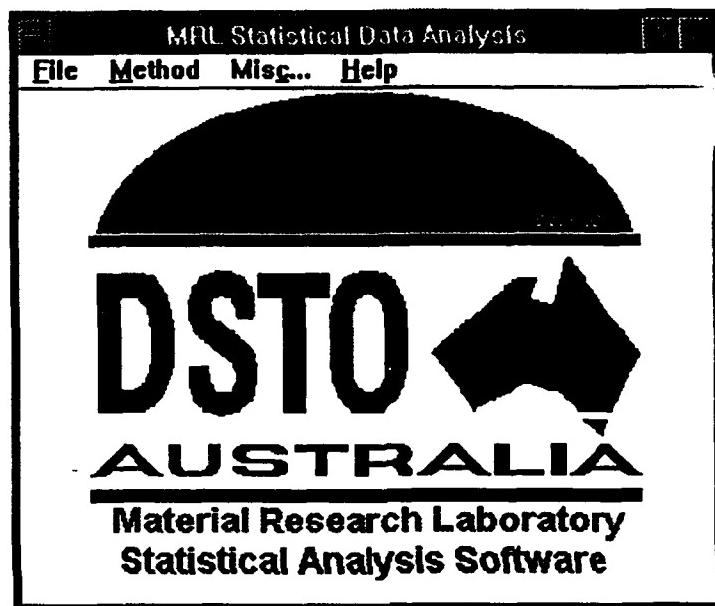


Figure 1. Main application window with four menu items

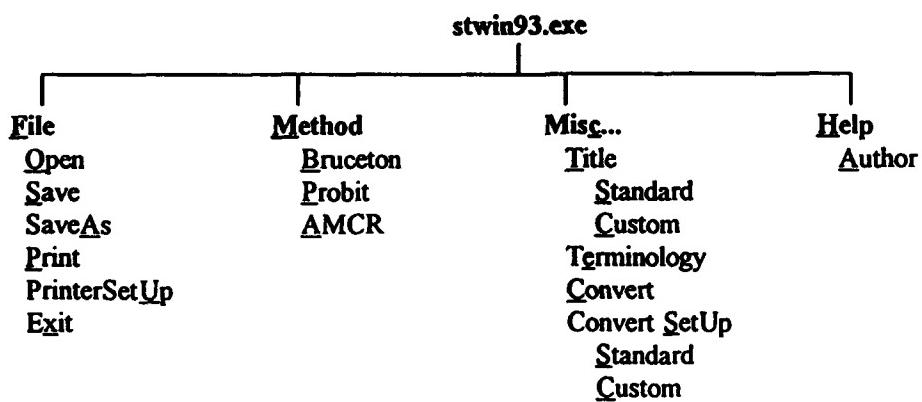


Figure 2. Program's menu items

3.3.1 File Menu

File menu enables users to load existing data files, save data, select an output device for printing, and exit the application program.

File|Open command enables the user to quickly recall a previously saved data file from disk. If the required data file is not listed on the Files list box, select a new drive, directory or select a different file type.

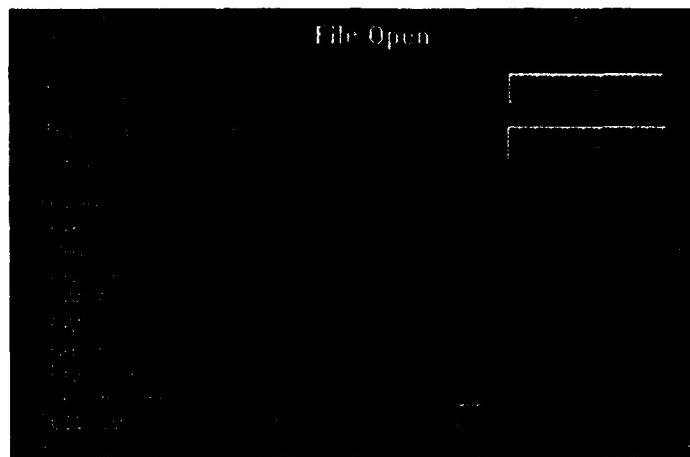


Figure 3. File Open dialog box

Filename input box prompts the user to enter the filename explicitly or using the DOS wildcards such as * and ? to filter out unwanted files. For more information on DOS wildcards, refer to DOS documentation.

Files list box lists files in the current directory. Depending on what is on the input box, various filenames will appear in this list box. When the program is initially called up, the wildcard appear on the input box is *.* which will list all filenames in current directory. Once an analysis method is selected, the filename extension is changed to an appropriate one, ie. *.BRU for Bruceton, *.PRO for Probit and *.AMC for AMCR file type. Hence, only the relevant file type is displayed.

Directories list box lists the directories and drives available on the system.

Note: In opening an existing data file, the default or current settings will be changed to the settings specified in that file. This is extremely handy in terms of editing the Experimental dialog box (Figure 9).

File|Save command saves the current settings, experimental information and raw data to disk under the specified filename. The first time the data is saved, the Save command function as the SaveAs command. Refer to Appendix III for file format details. For easy file referencing, it is recommended the following file extensions should be used,

Bruceton data file,	filename.BRU
Probit data file,	filename.PRO
AMCR data file,	filename.AMC

File|Save As command enables the user to save an unnamed data file, ie. new data set, or save an existing or updated data files under a different name, different directory or different disk drive. In the input box, type in the filename, select the disk drive and directory required, then select OK.

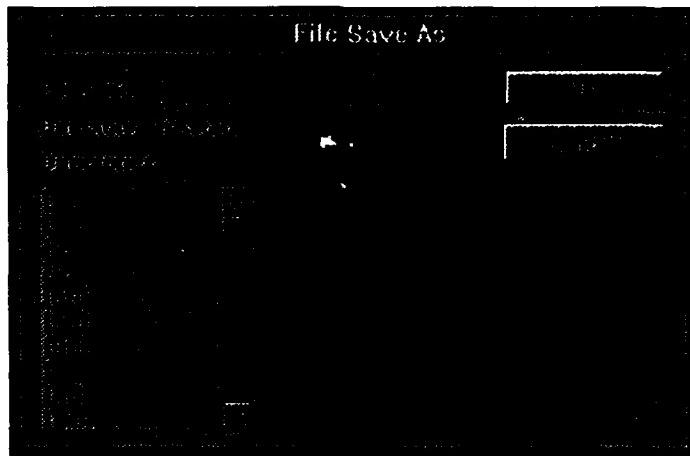


Figure 4. SaveAs dialog box

Filename input box prompts the user to enter a new filename.

Directories list box lists the directories and drives available on the system in which data may be saved.

File|Print command enables the user to produce hard copies of analysed results. To cancel current print job, select Cancel button in the Printing dialog box that will appear on the screen until the current print job is finished printing. It is a good practise to save the data before printing. That way, if a printer error or other problems occur, data is not lost. Copies of the printed output from the HP LaserJet III printer are shown in Appendix IV.

File|PrinterSet Up command enables the user to select a printer that has already been installed on the system. For more information on installing printer driver software, refer to Windows documentation. When selected, it calls up a Select-Printer dialog box showing the current default printer used as in Figure 5.

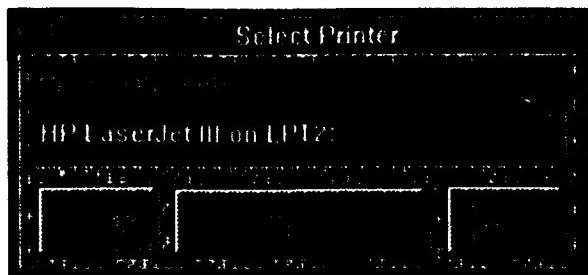


Figure 5. Select-Printer dialog box

Down Arrow (**↓**) button lists the available printer(s) available for use. Here the user can select a preferred printer as a default printer.

Setup button calls up a separate Printer Setup dialog box which enables the user to modify printer settings, such as different paper size, orientation, source of paper, graphics resolution, etc. For more information, refer to Windows documentation. The settings used to obtain the printed copies in Appendix IV are as follows,

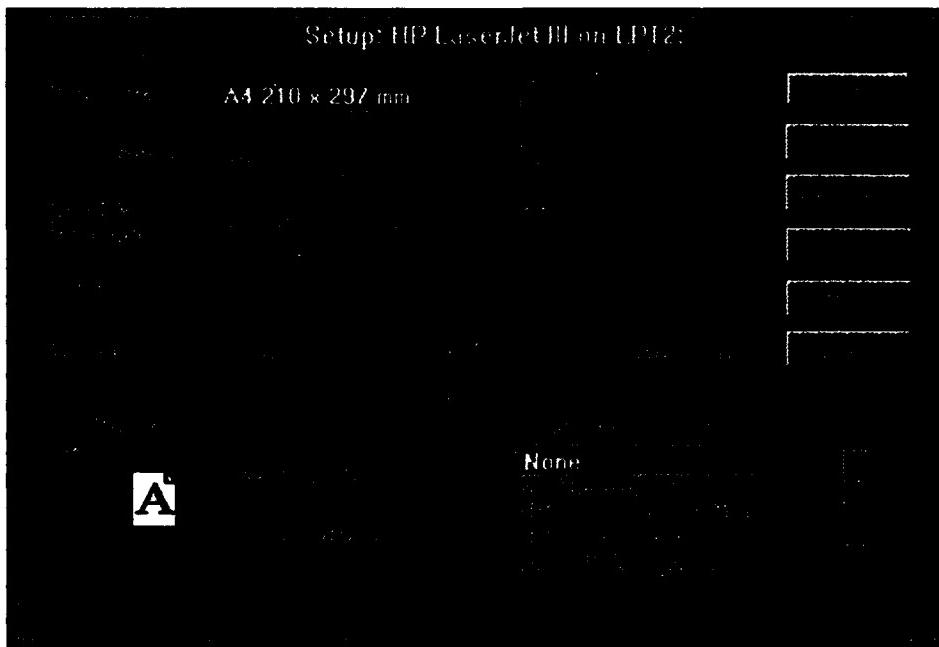


Figure 5a. Printer Setup dialog box

File|Exit command quits the application program and returns to the previous active window. When the exit command is selected, a Confirmation dialog box appears on the screen, to confirm the exit command. Furthermore, if the data is not saved, it will prompt the user to save the data.

3.3.2 Method Menu

Method menu enables the user to select the three methods of analysis available.

Method|Bruceton command enables the user to invoke the Bruceton analysis method. When selected, a Bruceton input dialog box appears, allowing the user to enter analysis conditions and the data to be processed. (Figure 6)

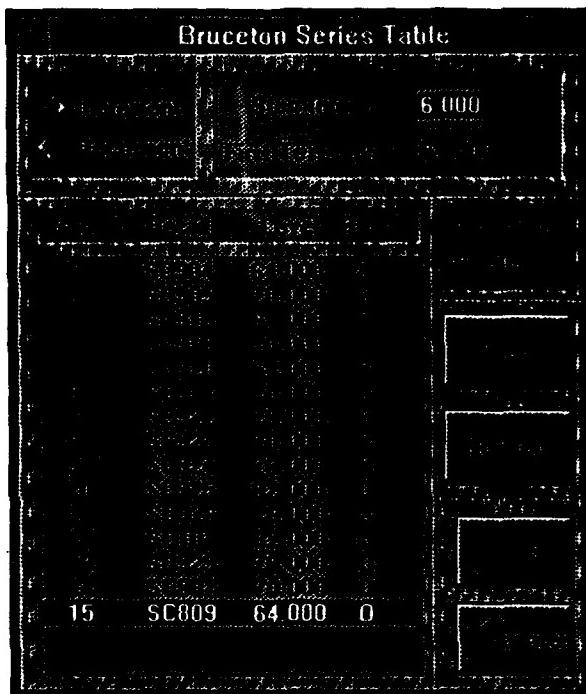


Figure 6. Bruceton input dialog box

Increment or Decrement radio button indicates the type of stepping method used in the Bruceton up-down scheme. For example, Increment checked means step up a level when detonation occurs, or alternatively, Decrement checked means step down a level when detonation occurs. Default is Increment checked.

Step Interval input box requires the user to enter the stepping size between levels.

First Test Level input box requires the user to enter the first Bruceton test level. The combination of these two inputs permits the automatic data determination feature to be implemented.

Shot Detail input box is optional. This feature is implemented to allow cross reference between the input data and the experimental records. Three recognisable formats are implemented;

First is the default, where there is no value entered in the input box, it assumes the first shot starts at 1 and then increments by one in subsequent shots, ie. 1, 2, 3, etc.

The second format is where the user enters the initial shot number, and the number is automatically incremented by one between shots, ie. 168, 169, 170, etc.

The third format permits character input, where the user supplies the initial shot index. This shot index must be preceded by two characters, ie. SC10001, SC10002, SC10003, SC1004, etc.

Of course, the three formats can be mixed together, ie. 168, 169, 2, 3, SC1001, 170, SC1002, etc. All three formats have a maximum of eight characters.

Fire button implies that a shot resulted in detonation, and the level increments or decrements accordingly.

NoFire button implies that a shot resulted in non-detonation, and again, the level increments or decrements accordingly.

Bruceton level list box lists the shot number, shot details, test level and result of the shots recorded. A scroll bar will appear on the right side if the number of shots recorded exceeds the length of the list box. That way, the user can scroll up or down the long list of shots.

To alter any recorded shot, the user double-clicks the mouse on the required shot. This produces a separate dialog box asking for Delete or Modify command. The Modify command modifies the result of the shot and automatically updates any shots that follow. The Delete command can be carried out only if the last recorded shot is selected.

Note: A limit of two hundred shots has been implemented.

OK button closes the Bruceton input dialog box, saves the data to memory, performs the calculation, and displays the results and input parameters onto a Bruceton result window. A sample of Bruceton result window is shown in Figure 6a.

Cancel button closes the Bruceton input dialog box and returns control to the main application window.

Note: No inputs or settings can be altered in the middle of data input, ie. the step interval, the first test level input box and the Increment/Decrement radio button cannot be altered after the Fire or NoFire button is depressed.

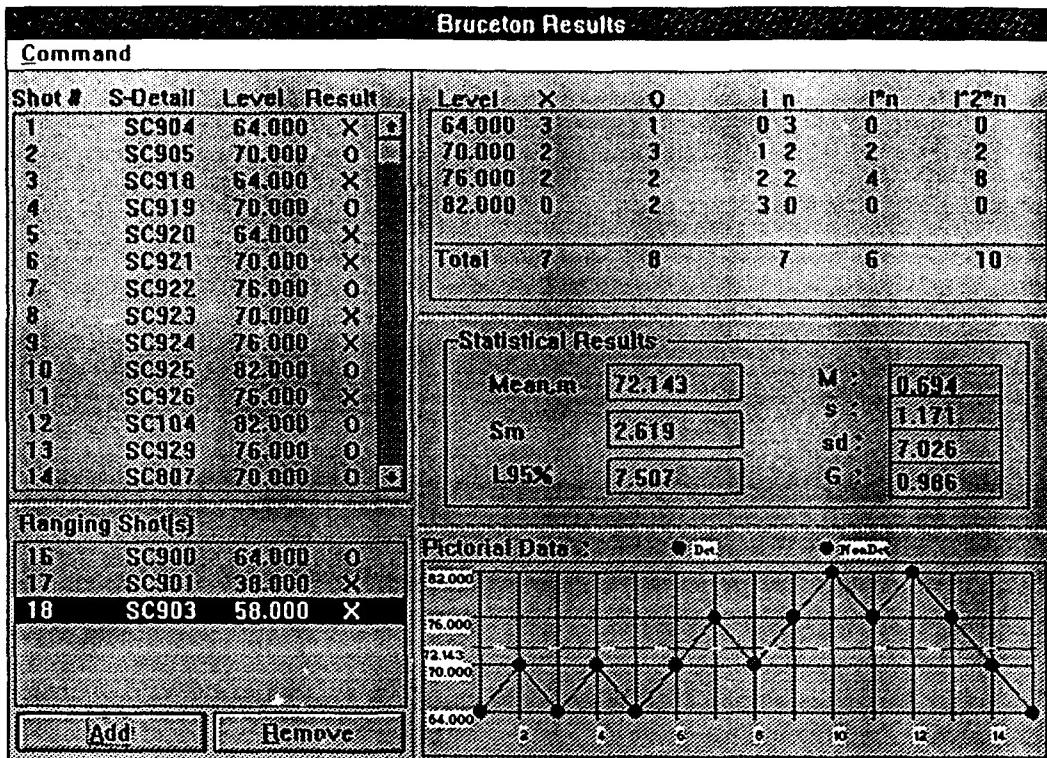


Figure 6a. Bruceton result window

Add button permits the user to add ranging shots to existing Bruceton data.

Remove button enables the user to delete existing ranging shots.

Command|GoBack command in this window allows the user to go back to Bruceton input dialog box to correct or update data, and returns with an updated Bruceton result window.

Command|Done quits the Bruceton result window and returns to the main application window.

Note: The ranging shot(s) is for user information only, it is not processed by the Bruceton analysis. On the hardcopy, the ranging shots are distinguished from the Bruceton data by an asterisk (*) preceding the shot number.

Method| Probit command enables the user to invoke the probit analysis method. When selected, a probit input dialog box appears, allowing the user to input probit data.

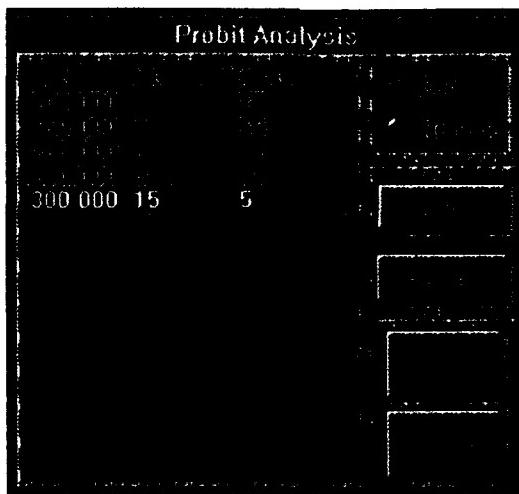


Figure 7. Probit input dialog box

Log or NonLog radio button enables the user to select either log or non-log test levels before the probit calculation begins. To avoid negative results a log-normal distribution is recommended. Therefore, Log is set as default.

Note: If the samples are already log-transformed, select the NonLog setting.

Add button lets the user add data to the probit list box. A maximum of thirty levels is permitted. Depressing the Add button calls up another probit formatted dialog box (see Figure 7a), which requires the user to enter the value for the test level, the total number of fires and no-fires at each level. OK button closes the probit formatted dialog box, and adds the data to the probit list box. Cancel button closes the probit formatted dialog box, without adding data to the probit list box.

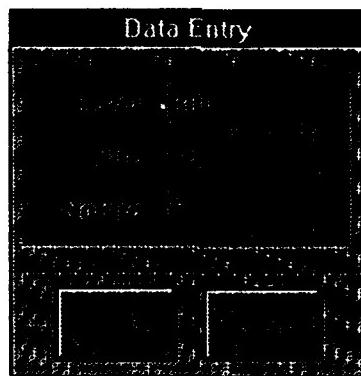


Figure 7a. Probit formatted dialog box

Delete button lets the user remove recorded data from the probit list box. To remove data from the list, select the data to be deleted using the mouse and then depress the Delete button.

OK button closes the probit input dialog box, saves and processes the data using the probit analysis method. Probit result window; depicted Figure 7b., displays various calculated parameters and results.

Cancel button closes the probit input dialog box and returns to the main application window.

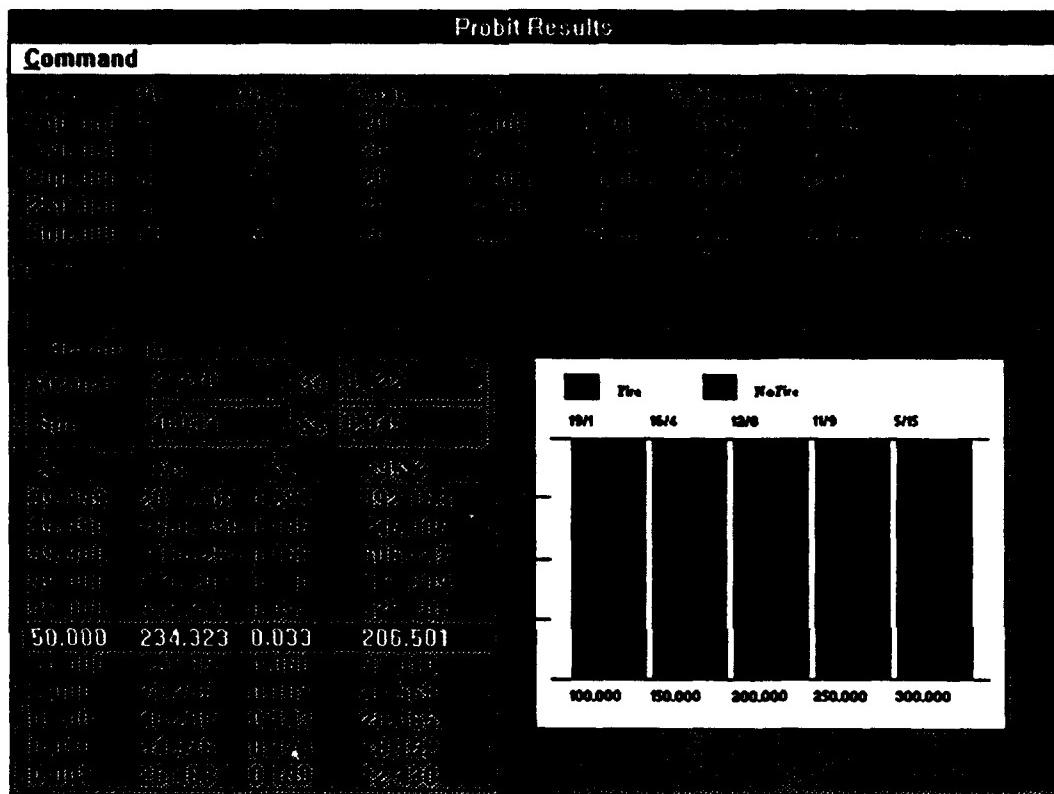


Figure 7b. Probit result window

Command| GoBack and **Command| Done** functions exactly the same as described in Bruceton result window section.

Note: To modify data, double-click the data point using the mouse. The probit formatted dialog box will appear allowing the user to perform the necessary changes.

Method|AMCR command enables the user to invoke the AMCR analysis method. When selected, an AMCR input dialog box appears, allowing the user to enter AMCR data for processing.

The AMCR input dialog box has a similar layout and functions as that of the probit input dialog box, except that the Log or NonLog radio button does not applied. For more information, refer to probit command section. The AMCR result window is shown in Figure 8. The necessity to have the first test level all no-fires and the last test level all fires is depicted below.

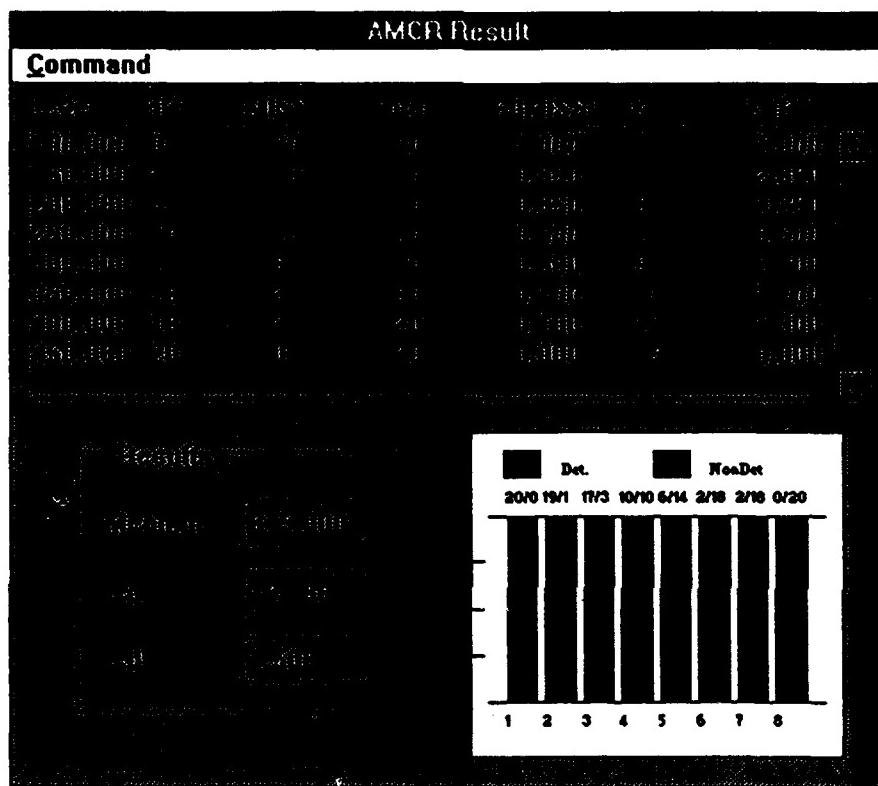


Figure 8. AMCR result window

3.3.3 Misc... Menu

Miscellaneous menu enables the user to set the preferred terminology, input experimental details, and update old file format.

Misc...|Title lets the user enter experimental details to be included as part of the printout. There are two experimental detail formats; Standard and Custom format.

Misc...|Title|Standard command calls up a standard experimental detail dialog box. This dialog box, as in Figure 9, has the standard field names such as explosive composition, density, etc. All the user needs to do is to type in the relevant information corresponding to field names. Of course, this is optional. If no information is entered, no detail is printed after the field names.

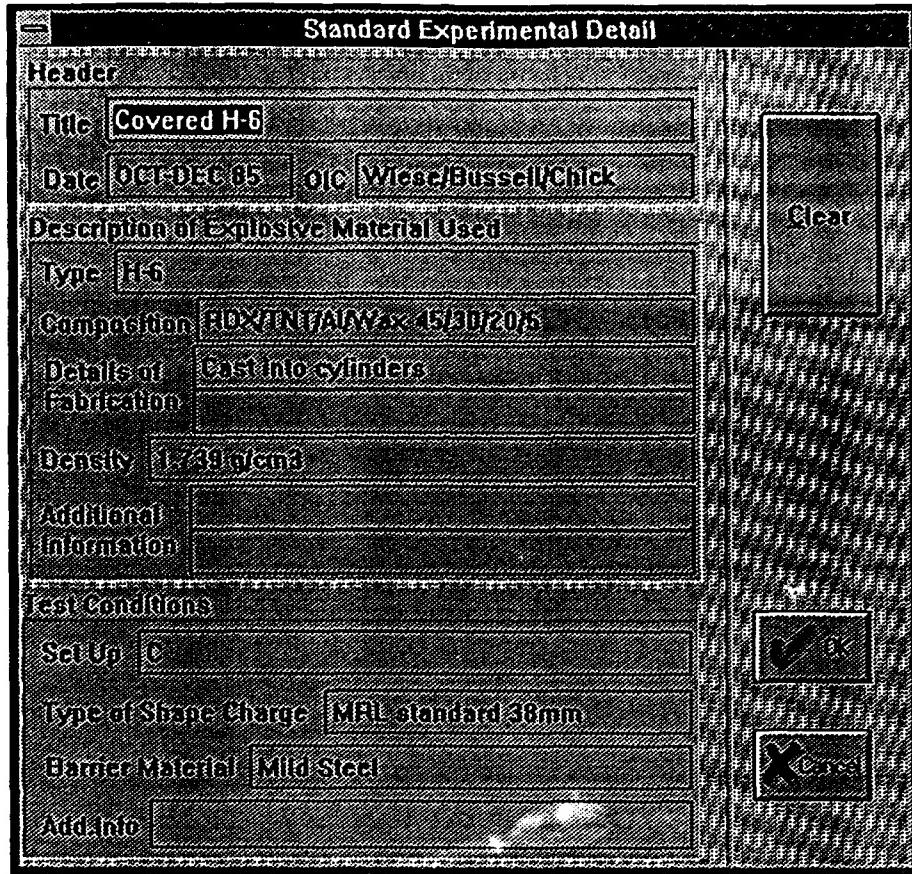


Figure 9. Standard experimental detail dialog box

Clear button enables the user to quickly clear all information appearing on the input boxes. Once cleared, all information is erased from the memory. Therefore, for minor alterations edit the field information individually.

Note: Experimental details are stored with each data file and can be recalled.

OK button closes the dialog box and saves all the information that's on the input boxes.

Cancel button closes the dialog box without saving the information.

Misc...[Title]Custom command calls up a custom experimental detail dialog box. In this empty dialog box, the user needs to enter the preferred field names as well as relevant information with respect to the field names. Refer to Appendix IV, Figures 4,5,6,7 and 8 for examples. Again, if no field name or information is entered, a blank space is printed. Buttons that appear on this dialog box has the same function as that of Misc...[Title]Standard.

Misc...|Preference command enables the user to select predefined terminology and the units system to appear on the printout. When selected, the dialog box allows the user to choose the preferred system.

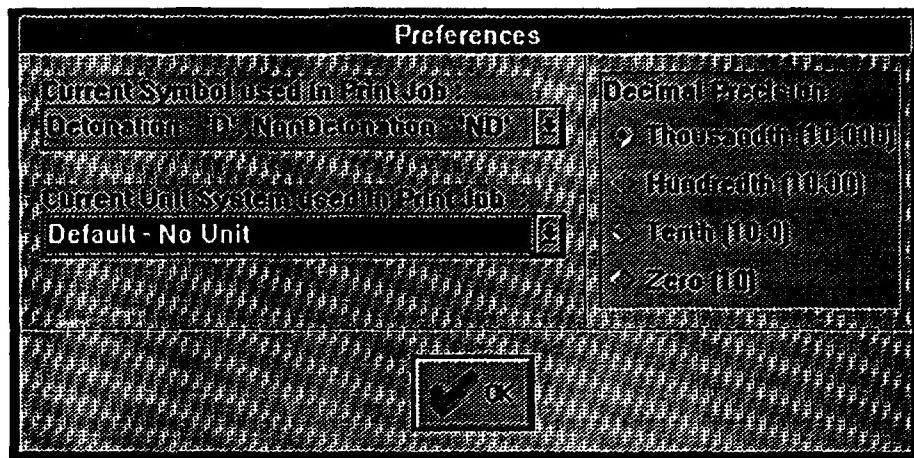


Figure 10. Preference dialog box

Predefined Terminologies:

Detonation and NonDetonation	-	D and ND *
Fire and NoFire	-	F and NF
Hit and Miss	-	H and M
Success and Failure	-	S and F

Predefined Unit system :

None	-	Blank *
Millimetre	-	mm
Centimetre	-	cm
Meter	-	m
Inch	-	in

Decimal Precision :

Thousandth	-	3 decimal places *
Hundredth	-	2 decimal places
Tenth	-	1 decimal places
Zero	-	No decimal place

* denotes default settings

Misc...|Convert command enables the user to convert an existing old data file format to current data file format. There are two forms of data file conversion; Standard and Custom format. The difference between the two is that Standard conversion assumes all settings use the default value (standard field names, Detonation/NonDetonation, no unit system, etc.), whereas, Custom conversion requires the user to manually fix the settings through various dialog boxes during the conversion process. These dialog boxes are the preference select and the experimental detail input dialog boxes. Refer to above for dialog box details.

Note: All data files saved using the DOS version of the computer model are considered old file format.

Misc...|Convert SetUp command enables the user to select the conversion process. These are the type of data file and the type of format conversion. When selected it calls up a ConvertSetup dialog box. Here the user can select the type of data file (Bruceton, Probit or AMCR type) and the format of the converted file (Standard or Custom). Default setting uses Bruceton file type and the Standard format.

3.3.4 Help Menu

Help menu enables the user to call up help information.

Help|Author command calls up a programmer detail dialog box for enquiries.

3.4 Limitations and Extensions

In order to obtain reliable Bruceton results, at least fifty data points are ideally required. The computer model permits up to two hundred data points, which should be sufficient for most tests. Likewise, a maximum of thirty ranging shots are possible. Due to space limitations on A4 size paper, a maximum of fifty shots can be printed in the table, but the whole Bruceton series is graphically represented.

Probit and AMCR data analysis have a limit of thirty levels, and the total number of data points on each level should be less than one thousand. A minimum of three levels are required.

Note: All limitations above are software restriction and are extendable.

Further extensions to the computer model could incorporate other commonly used statistical data analysis methods and the enhancement of existing algorithms.

4. Application of the Computer Model to Explosive Testing

The software package has been successfully applied to several tests at MRL concerned with estimating the sensitivity of explosive materials and the reliability of explosive devices. As a consequence of the user evaluation, the software was developed to Windows standards, so it is easy to use, yet flexible enough to accommodate various tests. And the printout format has been tailored to produce hardcopy in a form ready for reporting, presentation and storage. The tests serviced by the statistical software package are described below and examples of the resultant printout are given in Appendix IV.

4.1 The Jet Sensitivity test

4.1.1 General description of test.

The jet sensitivity test [5] was developed at MRL to investigate the sensitivity of both bare and covered explosives to shape charge jets. The experimental set-ups for assessing the sensitivity of both covered and bare explosives are depicted in Appendix V, Figure 1 and 2 respectively.

The covered explosive configuration was designed to simulate the cross section of a munition case and explosive filling penetrated by a shape charge jet. The confinement of the near and far side of the munition casing is represented by the cover and witness plate respectively. The standoff distance between the shape charge and the cover is to allow the jet to develop after the shape charge is initiated. It is important that the geometry of the receptor is of sufficient size to avoid complications from shocks reflected from the side and witness block interfaces.

A similar set-up is applied to bare explosive configurations except that an additional 15 mm air gap is incorporated between the cover and the receptor explosive. This arrangement was designed to remove the effect of the precursor waves (resulting from jet impact and jet penetration of the barrier) [6] from affecting the explosive.

The sensitivity of the explosive is expressed as the thickness of the cover material which produces a 50% probability of detonation. Variation of the cover thickness changes the jet characteristics, hence the velocity of the jet and shock entering the explosive. Thus increasing the cover thickness decreases the jet and precursor wave velocities and vice versa.

As in other tests of critical 'go, no-go' behaviour, the results must be interpreted statistically. A decision to increase or decrease the cover thickness is depended on the previous test result. A deep rounded dent on the witness plate indicates that the test explosive detonated, whereas no dent indicates a non-detonation. If in the test procedure, the charge detonates then the cover thickness is increased by a fixed thickness and if it fails to detonate then the cover thickness is decreased by the same thickness. Such an 'up-down' procedure is continued until a regular pattern of detonations and non-detonations is obtained. The results are then analysed statistically [1] to give the mean cover thickness the standard error and the 95% confidence limit. This critical cover thickness represents the detonation and non-detonation threshold for the receptor explosive.

4.1.2 Application of the software package.

A typical test schedule for a MRL jet sensitivity test is shown in Appendix IV, Figures 1; this includes the results for the statistical analysis of the data. The hardcopy from the software of the results is shown in Appendix IV, Figures 2a and 2b. Figure 2a represents a set of data collected from a jet sensitivity test on covered Composition-B explosive. Ideally, a large data sample is required to give a reasonable estimate. However, in practice, ten to twenty-five samples are usually the case. It uses the Bruceton analysis to determine the critical cover thickness (m), standard error (Sm) and the 95% confidence limit ($L95\%(m)$).

Appendix IV, Figure 2a, illustrates the explosive under test was a 38 mm diameter by 50 mm length Composition-B cylinder and that two cylinders were stacked on top of each other to give a total charge length of 100 mm. The test set-up was type 'C', and the explosive was covered with a mild steel barrier.

The numerical table displays the detail of the shots performed on a particular test. Starting with a 63.6 mm mild steel cover thickness (Test Level), the result was a non-detonation, ND, the cover thickness was then decreased by 6.4 mm (Step Size) to 57.2 mm where the charge detonated, D. The subsequent cover thickness was increment or decrement accordingly for twenty one shots. The printout shows that the step-up scheme was employed to the Bruceton Analysis when a detonation resulted. The graphical representation provides a clearer view of the data set. The "Shot Detail" column represents the user's own reference or catalogue number of each individual shot. Notice, there are no ranging shots present on

figure 2a, but in most cases ranging shots are unavoidable, as depicted on Figure 2b. There are three ranging shots on Figure 2b. They are shot sequence numbers (No.) 16 to 18 and are highlighted by '*'.

The Statistical Results box displays the mean (m), the standard error (Sm), and the 95% confidence limit of the mean. Other supporting parameters such as the standard deviation (sd), the 95% confidence limit, s, M, and G values are also shown. Refer to Section 8 for symbol definition.

This neatly compacted printout is customised to encapsulate all the necessary test details and statistical data. Thus, the printout shows immediately how the test was performed, what apparatus was required to carry out the test and what result was achieved.

4.2 Gap Test

4.2.1 General description of test.

The MRL Small Scale Gap Test (SSGT) provides a simple way to determine the sensitivity of an explosive to initiation by shock waves. A donor charge generates a shock pressure of uniform magnitude that is transmitted to an acceptor charge through an attenuating barrier. Commonly, the inert material for the barrier consists of laminated brass shim. Variation to the thickness of this barrier alters the strength of the shock waves entering the acceptor, hence the result of the test. In doing so, one can determine the critical barrier thickness required to initiate detonation in acceptor charge. The larger the critical gap, the more shock sensitivity is the acceptor material.

To determine an accurate value of shock sensitivity (refers to the ease with which an explosive detonates in response to the entering of shock wave), ideally a large number of trials must be fired using gap thicknesses near the estimated critical gap value. The result of such testing, having the 'detonation, non-detonation' characteristics, can be statistically analysed. An up-down method is applied, whereby, in a sequence of trials, the thickness of the inert material or barrier is increased or decreased depending on whether the previous trial results in detonation or non-detonation. If the shot results in detonation the next shot is fired with an additional fixed gap (d) added to the existing gap thickness, if it fails to detonate the next shot is fired with a removal of the fixed gap thickness. Usually, twenty to thirty shots are required to complete a SSGT. Using the Dixon and Mood method [1], the 50% firing gap thickness, usually referred to as critical gap, the standard error and the 95% confidence limit can be determined.

The standard experimental set-up for the gap test [7] at MRL is shown in Appendix V, Figure 3. It consists of a donor charge, an inert material barrier or shock attenuator, an acceptor charge and a steel witness plate for detecting detonation; a deep dent on the plate indicates a detonation otherwise a non-detonation is resulted.

4.2.2 Application of the software package.

A typical test schedule for a MRL gap test (SSGT) is shown in Appendix IV, Figure 3; this includes the results for the statistical analysis of the data, which is comparable with the results produced by the hardcopy of the software package.

The data presented in Appendix IV, Figure 4 is obtained from a SSGT[7]. The explosive under test is PE4 with 88% RDX composition. Its density value is 1.59 Mg/m^3 .

The test is performed under ambient temperature using 2 mm brass sheet to make up the gap thickness. The Bruceton method is employed to determine the critical gap thickness (m) required to detonate the acceptor charge, its standard error (Sm) and the 95% confidence limit ($L95\%(m)$). The layout format and bruceton computation is similar to that described in the Jet Sensitivity Test (Section 4.1.2). The only difference is the terminology used to describe the test condition.. This is to ensure that terminology used is appropriate for this application.

4.3 Slapper Detonator Test

4.3.1 General description of test.

The slapper detonator has a short response time, is able to be precisely timed and employs insensitive high explosive. This detonator is therefore safer to handle and provides potentially more reliability and flexibility than any other standard detonator.

The slapper detonator consists of a capacitor, a flat transmission line, a fast acting switch and a thin metallic bridge foil. In intimate contact with the bridge foil is a thin sheet of insulating material, usually Kapton or Mylar, known as the flyer plate. Underneath the bridge foil is a tamper. The flyer plate is separated from the acceptor explosive by a short barrel. A typical laboratory set-up is shown in Appendix V, Figure 4.

When the capacitor is discharged rapidly, the necked down region of the bridge foil vaporises. The flyer plate is accelerated by the expanding gas to a velocity of several mm per μ s before impacting the acceptor explosive. At impact a high strength shock wave is transmitted into the explosive. This shock wave rapidly heats the explosive near the point of impact which results in the formation of a detonation wave.

The performance of the slapper detonator is determined by locating the mean firing energy, $E_{50\%}(m)$ that produces a detonation in the acceptor explosive. An up-down method [8] is employed to provide a $E_{50\%}$ point and standard deviation. The usual step size is between 5 and 10mJ. Sample sizes of about 20 shots are a practical limitation and are known to give a poor estimate of the standard deviation [1].

The assessment of the performance of different slapper detonators is based on the relative $E_{50\%}$ point for each design. In addition, all assessments are related to a standard design in order to investigate the effect of specific design changes.

4.3.2 Application of the software package.

Appendix IV, Figure 5 displays a total of eighteen shots are subjected to the Bruceton analysis, whereby the mean firing energy level (m), standard error (Sm) and the 95% confidence limit ($L95\%(m)$) can be estimated. Ideally, a large sample size should be subjected to Bruceton analysis to insure a reasonable result, but sample sizes of about twenty shots are a practical limitation. The bruceton stepping method used in this application is different from the Jet Sensitivity and Gap Sensitivity test, it employs the step-down method when the sample fire. This is apparent on the numerical table (or the graphical representation), it indicates that at the first firing energy level (Test Level), 185 mJ, a no-fire (NF) resulted and the next firing energy level is increased to 190 mJ, an increment (Step Size) of 5 mJ. At shot number 3, the firing energy level of 195 mJ, the sample fired (F), hence the next energy level is reduced to 190 mJ. Refer to Section 4.1.2 for layout descriptions and Section 8 for symbol definition.

4.4 Cap Sensitivity Test

4.4.1 General description of test.

MRL is involved with the study of detonators, caps and various primers. To ensure that they function properly when electrically-initiated from a weapon, they must pass stringent electrical tests to meet RADHAS (Radiation Hazards). The set-up for the electrically-initiated cap sensitivity test consists of a firing box and a firing chamber where the cap is initiated safely.

A typical conducting composition primer cap is shown in Appendix V, Figure 5. The hollow part of the assembly consists of an external cup, internal cup, insulating envelop, and contact stud insulating washer. Conducting composition and primer composition are pressed in to the cap and disc closed. The capacitor inside the firing box is charged up to a specific energy level (up to 500 volts) and is discharged onto the cap. With the rapid discharge time of the capacitor, a high current is released and flows down a finite number of conducting paths initiating localised heating (hot spots). The cap functions when a hot spot reacts at the ignition temperature of the composition.

Test is carried out at different voltage levels to initiate the device, then the Bruceton analysis method is employed to determine the mean and the standard deviation. Once the mean is determined, the first subgroup of the device can be initiated at a voltage around this mean. The process is repeated for a number of voltage levels. The number of caps that fires or no-fires at each voltage level is recorded for Probit or AMCR analysis. This process gives an estimate of the normal distribution performance of the device.

4.4.2 Application of the software package.

Appendix IV, Figure 6 depicts a probit printout. A series of five voltage levels incremented by fifty volts (the increments do not have to be constant) is used. A total of twenty shots are used at each level with the number of fires and no-fires recorded; this is also represented graphically. The Empirical Probit, Provisional Probit and Expected Probit are calculated for each voltage level. The "Statistical Results" box lists the percentages (%) corresponding to the mean sensitivities (M_x) and the standard errors (S_x) which are in non-log or log form depending on whether the original or the log-transformed data are used. The 95% left-hand confidence limits ($x_{95\%}$) are also listed. The "Mean & StdDev. Results for x" box displays the mean (m), the standard deviation of the mean (S_m), the standard deviation (sd) and the standard deviation of sd (S_s). The results in this box are relevant to the values in the "x" column on the numerical table (i.e. log or non-log).

Appendix IV, Figure 7 depicts an AMCR printout. The caps are subjected to eight voltage levels with a fifty volt increment. The AMCR method requires a constant increment. The first level is the first level at which all the samples failed to fire and the last level is the level at which all the samples fired. The number of fires and no-fires are listed together with the decimal fractions of the misfires (P_i), the variance factors (K_i) and the $K_i P_i$ values. The "Statistical Results" box contains the mean (m), the standard deviation corrected for test interval (sd), the standard deviation uncorrected for test interval (sd'). The two other parameters listed are the values of $K_i P_i$ and P_i summed over the levels. Each column on the bar chart represents the proportion of fires at each level.

5. Conclusion

A computer software package has been developed for the statistical analysis of data from the testing of explosive materials and devices. The package includes the choice of three statistical methods; Bruceton, Probit and AMCR. Advantages of the scheme include the rapid and accurate processing of data, reduction in human errors, and the printout is presentable and informative.

The package has been successfully adapted to and trialed with four small scale explosive tests.

6. Acknowledgments

I would like to thank the following people for their valuable suggestions and assistance; Mick Chick, Eric Northeast, John Waschl, Darren McQueen, Mike Wolfson, Horace Billon and Lance Redman.

7. References

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8. Glossary of Terms

Dialog Box	is a pop-up window indicating that the application expects some input from the user. It is closely related to displaying a window.
Menu	is a list of application items or commands that the user can select to perform an operation.
List Box	is a window filled with a list of items that the user can select from.
Radio Button	is a control button (usually circular in shape) that offers the user a selection and represents the state of the selection; ON or OFF. Radio buttons are usually grouped to provide the user with a choice of mutually exclusive buttons.
Edit/Input Box	is an area assigned to enable user to input text to be used by the program.
Scroll Bar	is a control indicating the relative position of a specific range along the List Box or Window. It can be either horizontal or vertical.
Mean, m	mean of the sample tested.
σ, sd	standard deviation of the sample tested.
σ_m, Sm	sample standard deviation/error of the mean.
μ_p	mean of the population.
σ_p	population standard deviation.
$t_{0.95}$	is given by the t distribution table for sum of sample tested.
x	test levels, ie. cover thickness, voltage level, gap thickness etc.
Y	represents the Empirical, Provisional and Expected Probit.
$\%$	observed percentage.
$\bar{x} \%, Mx$	mean of a given percentage threshold.
Sx	standard deviation of Mx or Log Mx
$L95\%$	is the 95% confidence limit, ie. $\pm t_{0.95} \sigma_m$.
$L95\%(m)$	95 percent confidence limit of the mean, ie. $m \pm t_{0.95} \sigma_m$.
$x95\%$	95 percent no-fire confidence limit, ie. $\bar{x} \% - t_{0.95} \sigma_m$.
sd'	standard deviation not corrected for test interval.
M	refer to equation 2.
s	refer to equation 3.
G	refer to section 2.1, C

Appendix I : Program Structured Diagrams

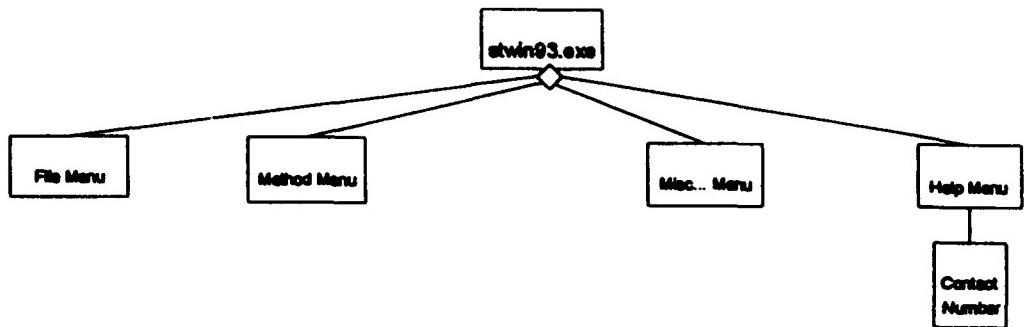


Figure 1. Main Structure Diagram

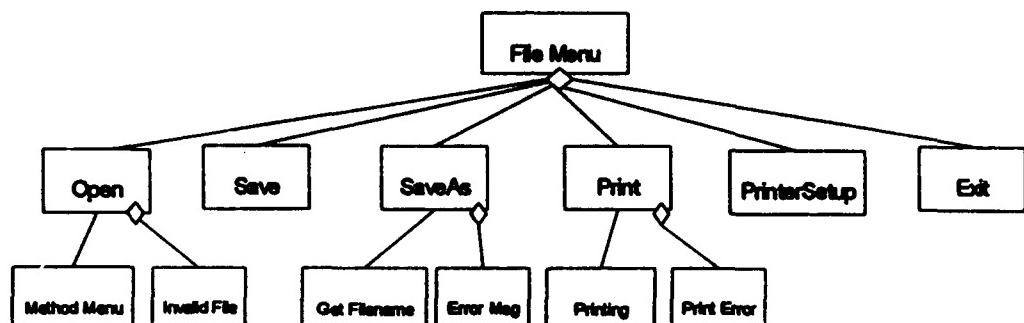


Figure 2. File Menu Structure Diagram

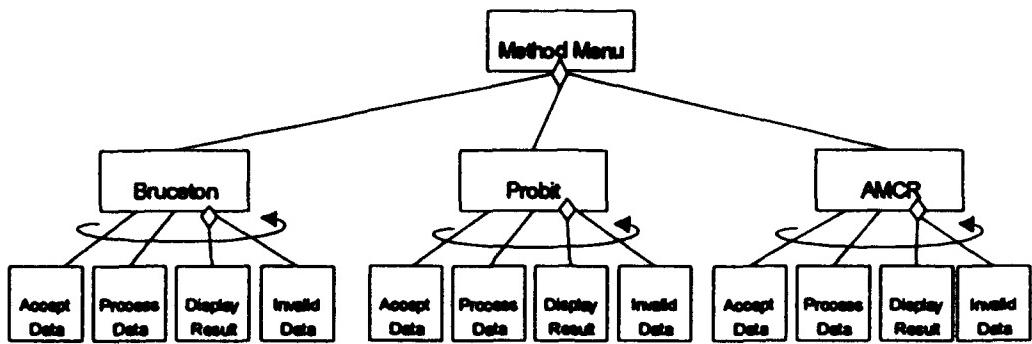


Figure 3. Method Menu Structure Diagram

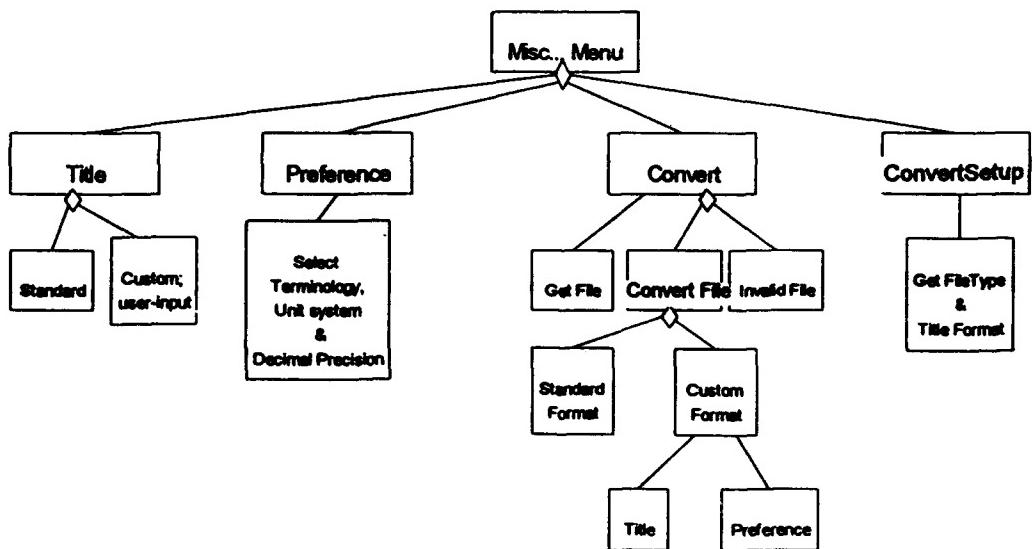
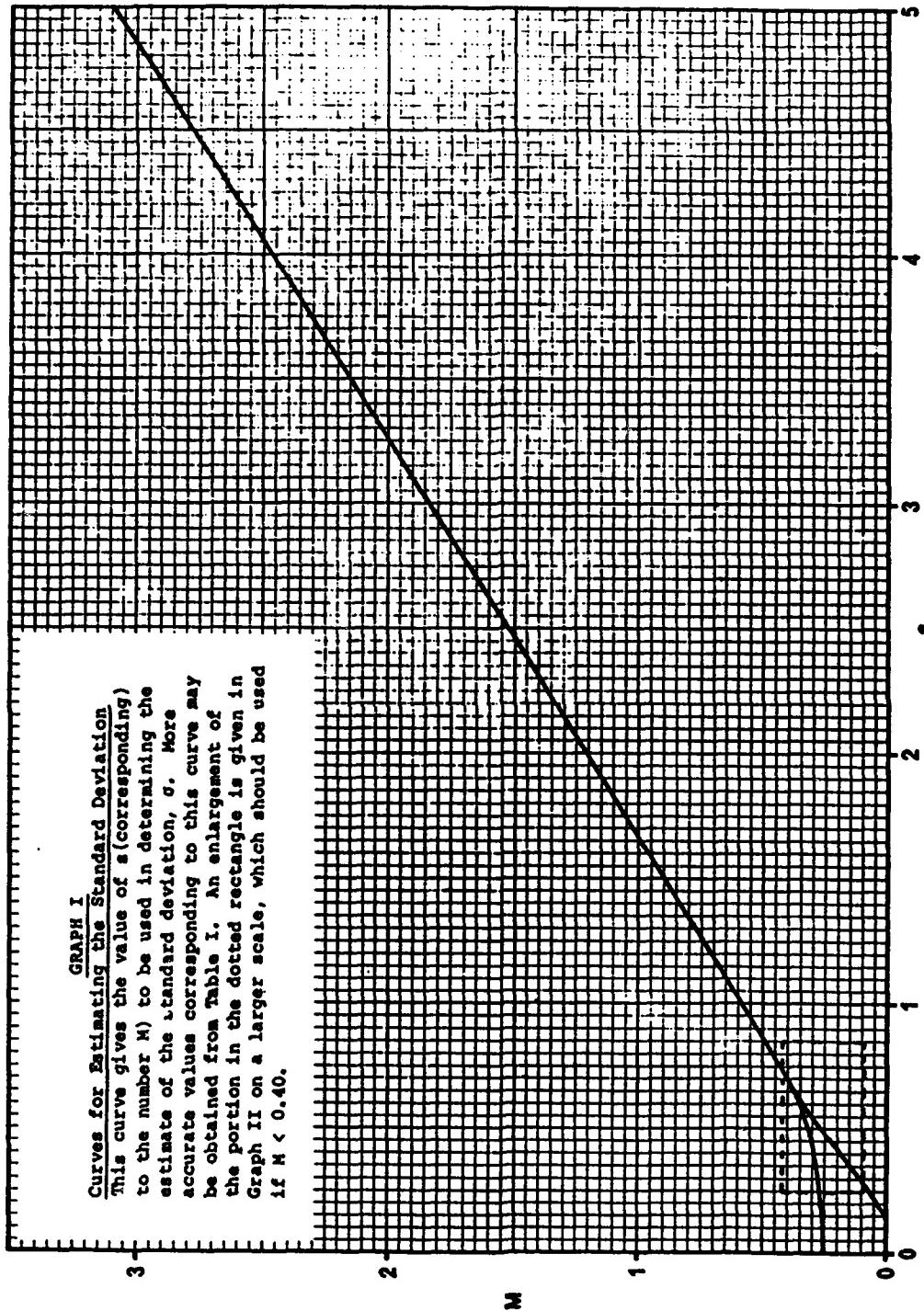
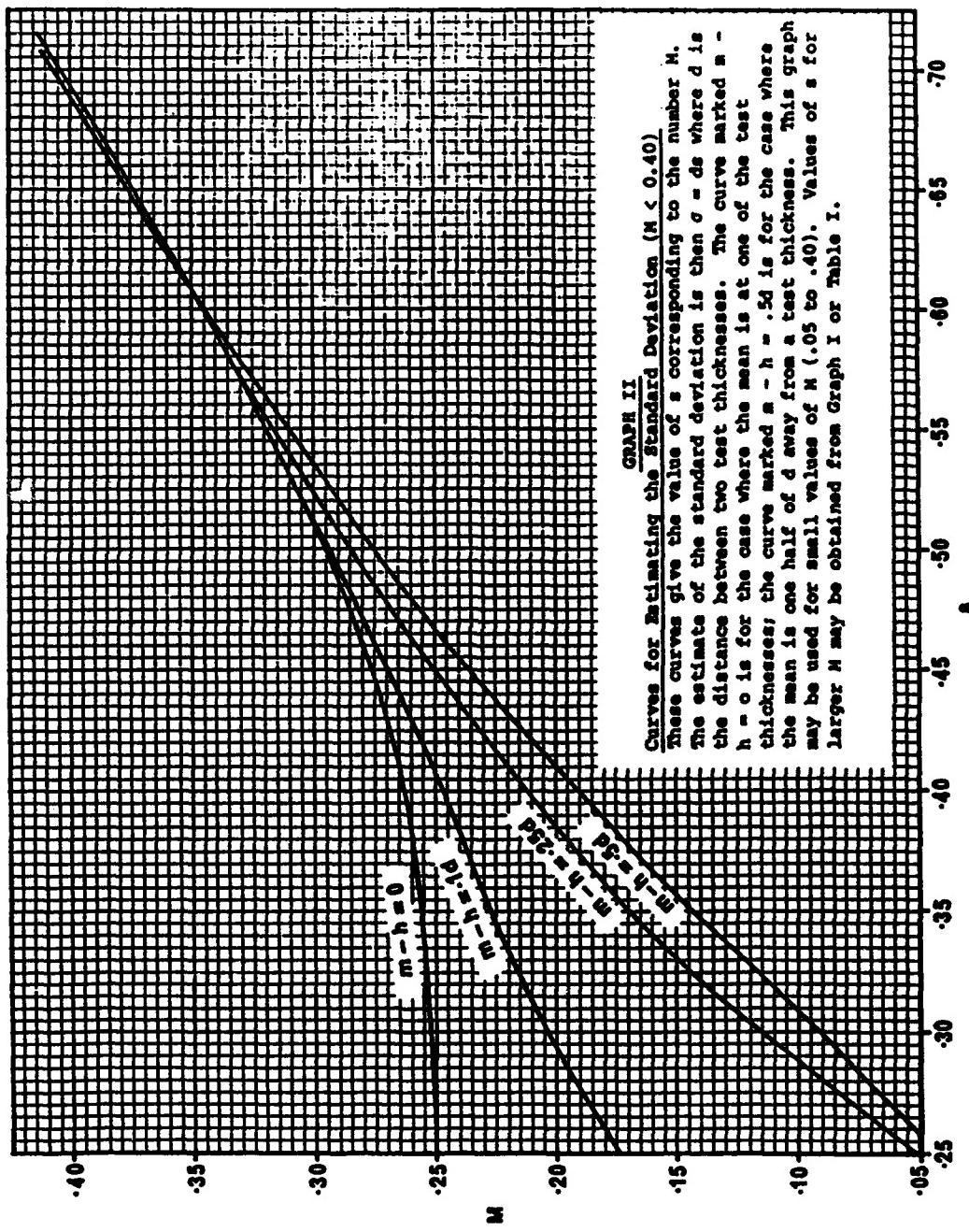


Figure 4. Miscellaneous Menu Structure Diagram

Appendix II : Bruceton Reference Graphs

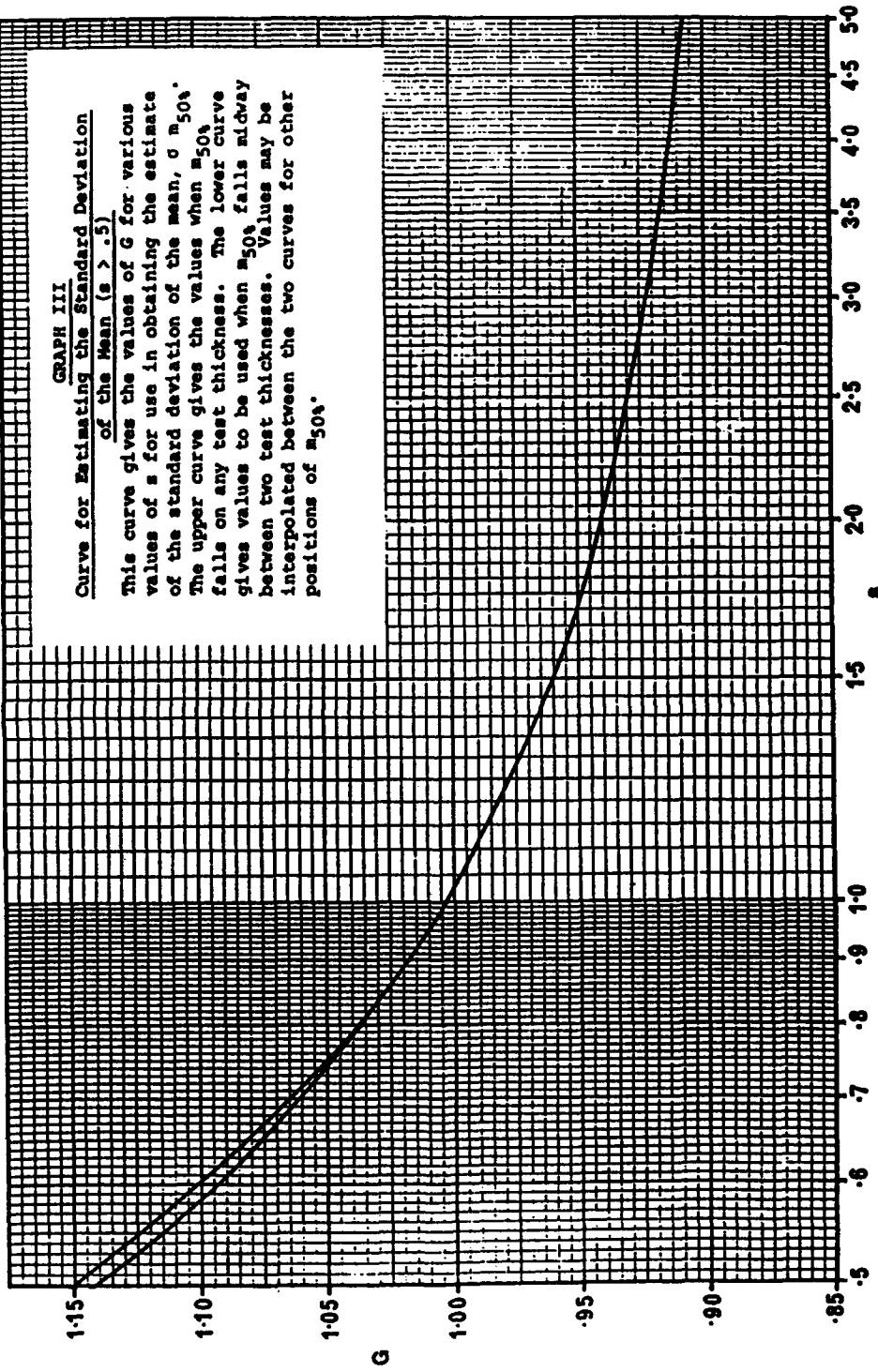
Graphs used in Dixon and Mood [1]





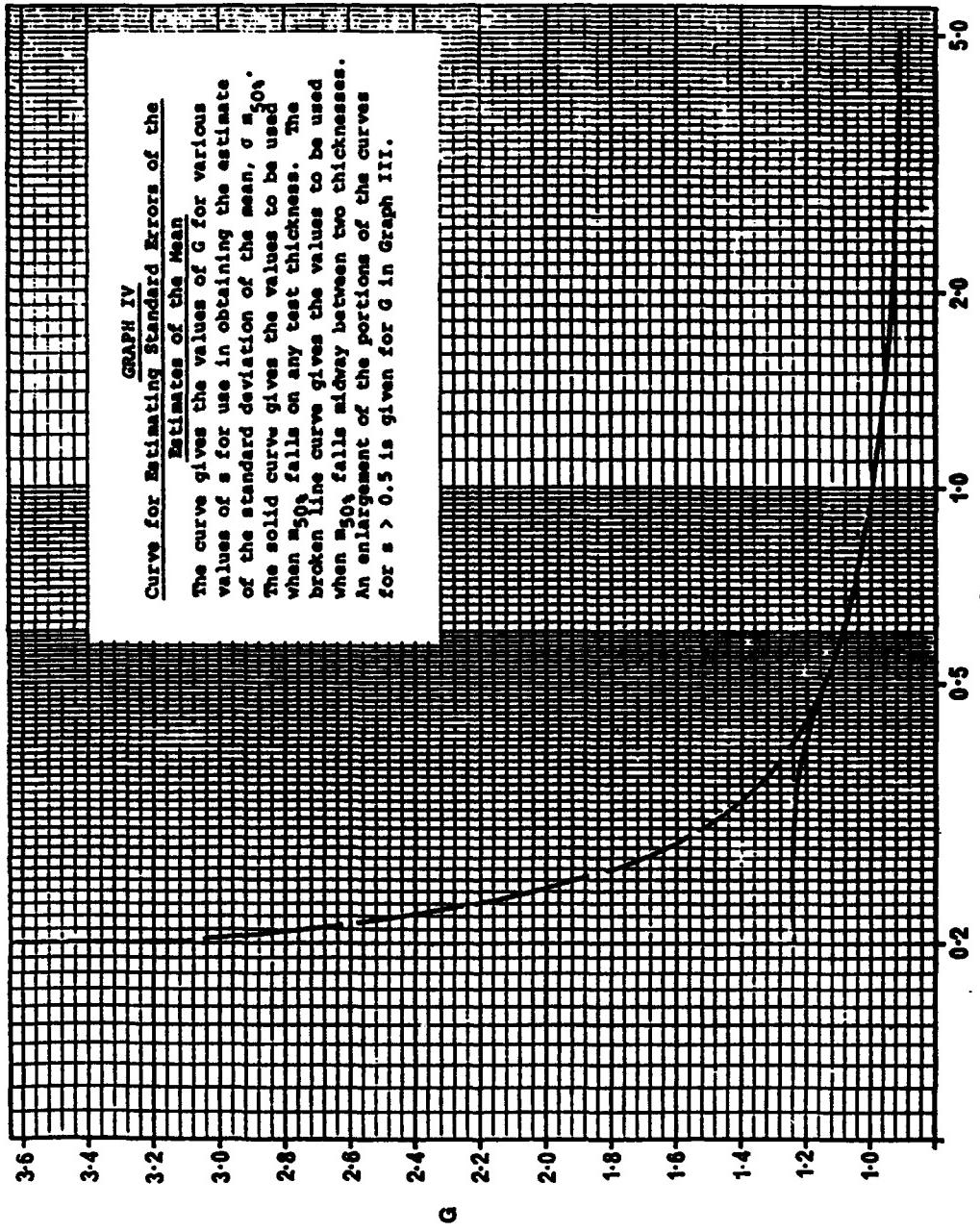
GRAPH III
Curve for Estimating the Standard Deviation

of the Mean ($s > .5$)
This curve gives the values of G for various
values of s for use in obtaining the estimate
of the standard deviation of the mean, $\sigma_{m50\%}$.
The upper curve gives the values when $m50\%$
falls on any test thickness. The lower curve
gives values to be used when $m50\%$ falls midway
between two test thicknesses. Values may be
interpolated between the two curves for other
positions of $m50\%$.



GRAPH IV
Curve for Estimating Standard Errors of the
Estimates of the Mean

The curve gives the values of G for various values of s for use in obtaining the estimate of the standard deviation of the mean, $s_{\bar{G}} = \frac{s}{\sqrt{G}}$. The solid curve gives the values to be used when 50% falls on any test thickness. The broken line curve gives the values to be used when 50% falls midway between two thicknesses. An enlargement of the portions of the curves for $s > 0.5$ is given for G in Graph III.



Appendix III : Input and Output Data File Format

All input and output data files are saved as standard ASCII format, so the content of the file can be viewed and modified outside the software, using other editor packages such as Turbo Pascal, qEdit, XTGold, etc.

Bruceton Data File Format :

- Line 1 : represent the file identifier and condition flags for the computer model.
- variable 1 is the statistical data file identifier
 - variable 2 is the method identifier
 - variable 3 is the experimental detail format identifier
 - variable 4 is the terminology identifier
 - variable 5 is the system unit identifier
 - variable 6-11 is not used. It is there for future enhancements without the need to convert old data format.
- Line 2-15 : represent the environment and condition in which the tests are conducted. These details correspond to field names and information in the computer model (Section 3.3.3).
- Line 16 : "INC" or "DEC" is the flag to determine the type of stepping methods.
"INC" represents an increment by a step interval on the test level, when a 'fire' is resulted, while "DEC" decrements the test level by a constant step interval when a 'fire' is detected.
- Line 17 : represent the number of Bruceton shots, step interval value and the number of ranging shots respectively.
- Line 18...n : represent the Bruceton series.
- variable 1 is the test level,
 - variable 2 is the result; '1' is 'Det.' and '0' is 'NonDet'.
 - variable 3 is the shot cross reference detail.
- Line n+1 : represent the first ranging shot in a series
- Line n+2... : represent the second, third, etc.

Probit and AMCR Data File Format :

- Line 1 : As in Bruceton format.
- Line 1-15 : As in Bruceton format.
- Line 16 : number of test levels in the series.
- Line 16+n : represents the series of probit data.
- variable 1 is the test level
 - variable 2 is the number shot results as a 'fire'
 - variable 3 is the number of shot results as a 'no-fire'

Appendix IV : Application Results and Outputs

Date of Test	OCT 1973	OTC	I. LEADERSHIP/A. RIX			
A. DESCRIPTION OF EXPLOSIVE MATERIAL TESTED						
Type	Composition B	Composition	ABD/TNT/WAX, 55/5/1			
Details of fabrication	Cast into 36 mm dia by 300 mm cylinders. Rudder removed.	Machined into 36 mm dia by 36 mm cylinders				
Density	1.65 Mg/m ³	Additional Data	Test charge length 100 mm (2 cylinders)			
B. TEST CONDITIONS						
Type of Shaped Charge	HAL STANDARD 26 mm dia	Set-up	Standard			
Cover Material	MILD STEEL	Additional Data	STANDARD TEST			

Date	FEBRUARY 1974	Assessor	M. CRICK	
smallest cover thickness (cm)	56.4 (mm)	Cover Thickness Interval (d)	6.4 (mm)	
Test Cover thickness (mm)	No. of Detections (use + in eqn 1)	No. of Non-Detections (use - in eqn 1)	I n ₁	I n ₁
A (c) 56.4	1	0	0	0
S 57.2	0	1	0	0
C 63.6	0	3	0	0
E			2	0
N			4	0
D			4	0
Z			7	0
N			4	0
G			0	0
			TOTAL = 16	TOTAL = 16

22. c - smallest cover thickness used in calculations
 n - number of doses or number of determinations - if different use whichever has the smaller total number

$$(1) \quad R_{211} = c + d \left[\frac{x_{10}}{x_{n_1}} \right]^{1/2} V_2 - 20.3 + 2.95 = 22.4$$

$$(2) \quad n = \left[\frac{11^2 n_1}{\Sigma n_i} \right] - \left[\frac{\ln \frac{1}{n}}{\ln \frac{1}{n_1}} \right]^2 - 0.9 - 0.61 = 0.02$$

(13) - 6.2.1 (From Diction and Method 1960, 1 and Graphia 1 & 11)

(4) $G = \underline{1.3}$ (From Graph III & IV)

(5)	$\sigma = 24$	<u>- 1.94</u>	<u>0.94</u>
(6)	$\sigma_{\text{min}} = 76$	-	-

$$(7) \quad L_{351} \left(m_{301} \right) = m_{301} \pm 1.46 \quad \frac{\left| m_{301} - 1.2 \right|}{L_{301}}$$

$$B_{\text{min}} = \frac{19.0}{20.0} = 0.95 \quad B_{\text{max}} = \frac{19.0}{18.0} = 1.06 \quad B_{\text{avg}} = \frac{19.0}{19.0} = 1.00$$

Figure 1: A typical test schedule for MRL Jet Sensitivity Test.

Title : Covered Composition B
Date : 8/80-1/82 OIC : Learmonth/Chick

A. Description of Explosive Material Used

Type : Composition B

Composition : RDX/TNT/Wax 55/45/1

Fabrication : Cast into cylinders 38mm dia. x 50mm

Density : 1.65 g/cm³

Add_Info : Charge Length 100mm

B. Test Conditions

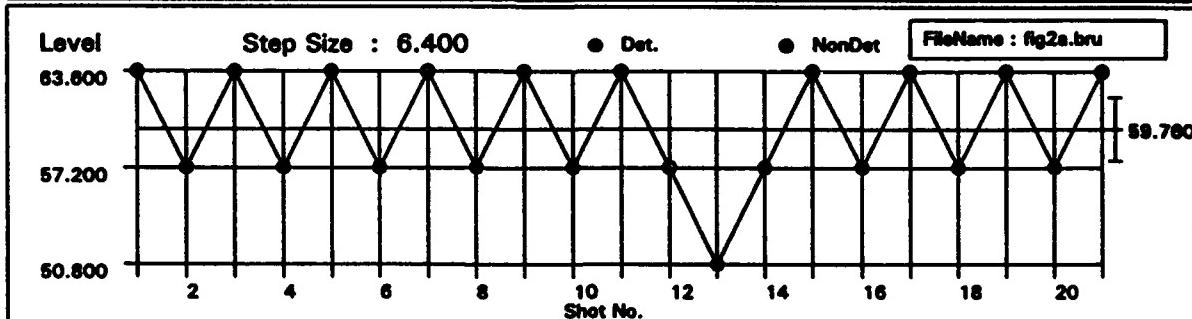
Set_Up : C

Type of Shape Charge : MRL standard 38mm

Barrier Material : Mild Steel

Add_Info :

No.	Shot Details	Test Level	Result	No.	Shot Details	Test Level	Result
1	SC521	63.600	ND	19	SC586	63.600	ND
2	SC567	57.200	D	20	SC584	57.200	D
3	SC522	63.600	ND	21	SC593	63.600	ND
4	SC568	57.200	D				
5	SC524	63.600	ND				
6	SC569	57.200	D				
7	SC526	63.600	ND				
8	SC570	57.200	D				
9	SC527	63.600	ND				
10	SC576	57.200	D				
11	SC528	63.600	ND				
12	SC577	57.200	ND				
13	SC522	50.800	D				
14	SC578	57.200	D				
15	SC529	63.600	ND				
16	SC579	57.200	D				
17	SC585	63.600	ND				
18	SC580	57.200	D				



Statistical Results :

Mean,m : 59.760

S_m : 0.839

L95%(m) : 61.886, 57.634

Other Parameters :

M : 0.090

G : 1.392

s : 0.298

L95% : 2.126

sd : 1.907

Figure 2a: Jet Sensitivity Test on covered Comp B.

Title : Covered H-6

Date : OCT-DEC 85 OIC : Wiese/Bussell/Chick

A. Description of Explosive Material Used

Type : H-6

Composition : RDX/TNT/Al/Wax 45/30/20/5

Fabrication : Cast into cylinders

Density : 1.739 g/cm³

Add_Info :

B. Test Conditions

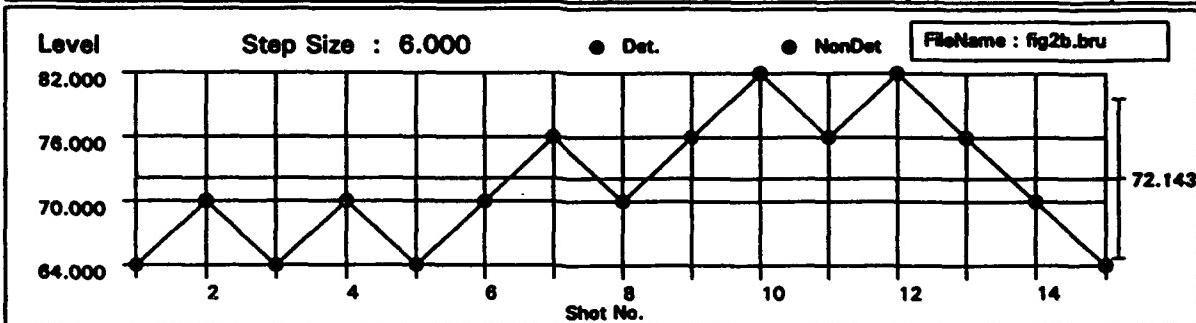
Set_Up : C

Type of Shape Charge : MRL standard 38mm

Barrier Material : Mild Steel

Add_Info :

No.	Shot Details	Test Level	Result	No.	Shot Details	Test Level	Result
1	SC904	64.000	D				
2	SC905	70.000	ND				
3	SC918	64.000	D				
4	SC919	70.000	ND				
5	SC920	64.000	D				
6	SC921	70.000	D				
7	SC922	76.000	ND				
8	SC923	70.000	D				
9	SC924	76.000	D				
10	SC925	82.000	ND				
11	SC926	76.000	D				
12	SC104	82.000	ND				
13	SC929	76.000	ND				
14	SC807	70.000	ND				
15	SC809	64.000	ND				
*16	SC900	64.000	ND				
*17	SC901	38.000	D				
*18	SC903	58.000	D				



Statistical Results :

Mean,m : 72.143

Sm : 2.619

L95%(m) : 79.650, 64.635

Other Parameters :

M : 0.694

s : 1.171

sd : 7.026

G : 0.986

L95% : 7.507

Figure 2b: Jet Sensitivity Test on covered H-6.

CAP TEST ASSESSMENT OF SMOKE SENSITIVITY

DATE OF TEST	12-2-62	OPERATOR	R. SONGUZI	TEST NO.	9/62
<u>A. DESCRIPTION OF EXPLOSIVE MATERIAL TESTED.</u>					
TYPE	P64	COMPOSITION		80% RDX	
DETAILS OF FABRICATION		ADDITIONAL INFORMATION		Lot. No.	60
DENSITY		1.59 g/cm ³		Impesp. No. 690	
<u>B. TEST CONDITIONS:</u>					
TYPE OF COVER	SCALE I				
MATERIAL	BRASS		BARREL THICKNESS INTERVAL & (in.)		
ADDITIONAL INFORMATION					

N.B. a = smallest skin thickness used in calculations
 n = number of detonations or non-detonations,

$$\begin{aligned} & \left(\frac{\partial^2}{\partial x_1^2} + \frac{\partial^2}{\partial x_2^2} + \dots + \frac{\partial^2}{\partial x_n^2} \right) u = f(x_1, x_2, \dots, x_n) \\ & u(x_1, x_2, \dots, x_n) = u_0(x_1, x_2, \dots, x_n) \end{aligned}$$

111 and Grainger 1 & 111

(4) $c = 1.000$ (From Graphs III and IV).

$$a = 4 \times 2 = \underline{1.15}$$

$$v \propto G^{-1/2} \pi^{1/2} \epsilon^{1/2} \approx 1.33 \times 1.060 = 0.411$$

$$\rho_{\text{magn}} = \frac{3.444}{\sqrt{E_2/E_1}}$$

$$(\text{sum} - 21.5 \cdot 2.95) \cdot 1.96 = \text{sum} - 12.1$$

- 22.555 and -

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$$\log_{10}(n_{\text{sites}}) = 21.6 \pm 0.69 = 22.356 \pm 20.70$$

Figure 3: A typical test schedule for MRI Shock Sensitivity Test.

Title : Gap Test Assessment of Shock Sensitivity

Date : 12-2-82 OIC :

A. Description of Explosive Material Used

TYPE : PE4

COMPOSITION : 88% RDX

DETAILS OF :

FABRICATION

DENSITY : 1.59 Mg/m³

ADD. DATA : Lot. No. 80, Incorp. No. 690

B. Test Conditions

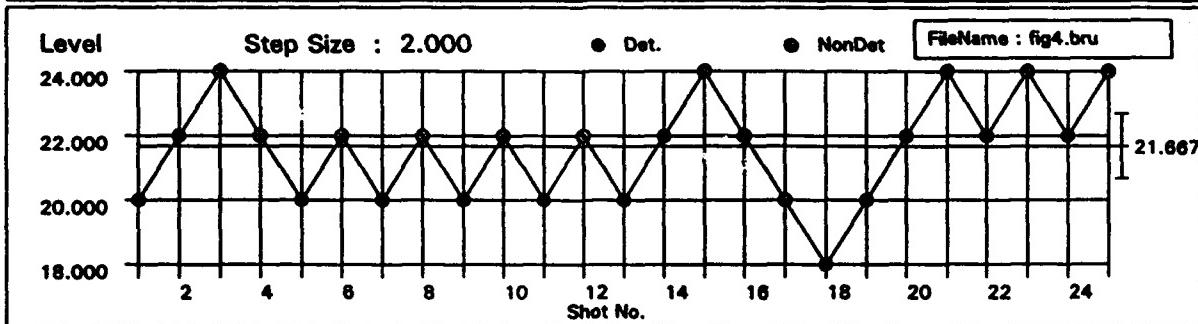
TEST TEMPERARURE : AMB

TYPE OF DONOR : Scale 1

BARRIER DETAILS : Brass, 2mm thickness interval

Add. INFORMATION :

No.	Shot Details	Test Level	Result	No.	Shot Details	Test Level	Result
1	1	20.000	D	19	19	20.000	D
2	2	22.000	D	20	20	22.000	D
3	3	24.000	ND	21	21	24.000	ND
4	4	22.000	ND	22	22	22.000	D
5	5	20.000	D	23	23	24.000	ND
6	6	22.000	ND	24	24	22.000	D
7	7	20.000	D	25	25	24.000	ND
8	8	22.000	ND				
9	9	20.000	D				
10	10	22.000	ND				
11	11	20.000	D				
12	12	22.000	ND				
13	13	20.000	D				
14	14	22.000	D				
15	15	24.000	ND				
16	16	22.000	ND				
17	17	20.000	ND				
18	18	18.000	D				



Statistical Results :

Mean,m : 21.667

Sm : 0.419

L95%(m) : 22.681, 20.652

Other Parameters :

M : 0.389

s : 0.677

sd : 1.354

G : 1.072

L95% : 1.014

Figure 4: Shock Sensitivity Test on PE-4, using customised title format.

Title : HNS 42

Date : 1990 OIC :

A. Description of Explosive Material Used

TYPE : HNS 42

SSA : ~42 m²/g

DENSITY : 90% TMD

ADD. DATA :

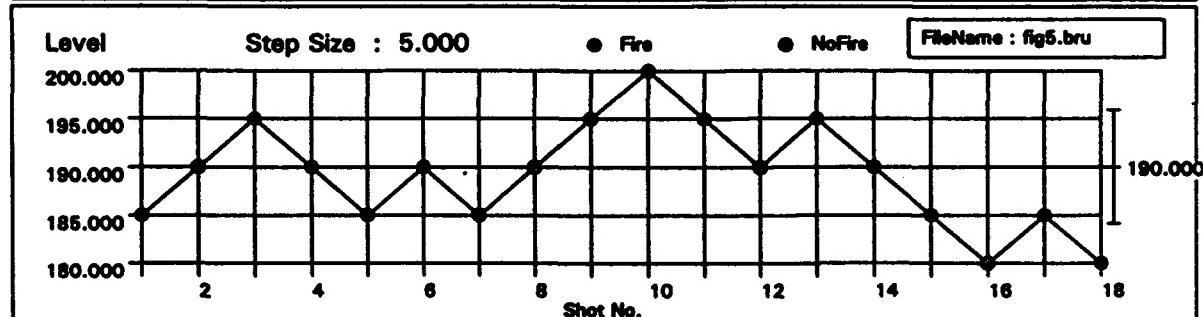
B. Test Conditions

SET-UP : Standard Slapper Detonator

TYPE OF DEVICE USED : 0.189uF capacitor

ADD. INFORMATION :

No.	Shot Details	Test Level	Result	No.	Shot Details	Test Level	Result
1	1	185.000	NF				
2	2	190.000	NF				
3	3	195.000	F				
4	4	190.000	F				
5	5	185.000	NF				
6	6	190.000	F				
7	7	185.000	NF				
8	8	190.000	NF				
9	9	195.000	NF				
10	10	200.000	F				
11	11	195.000	F				
12	12	190.000	NF				
13	13	195.000	F				
14	14	190.000	F				
15	15	185.000	F				
16	16	180.000	NF				
17	17	185.000	F				
18	18	180.000	F				



Statistical Results :

Mean,m : 190.000

Sm : 2.171

L95%(m) : 195.904, 184.096

Other Parameters :

M : 0.750

G : 0.973

s : 1.262

L95% : 5.904

sd : 6.310

Figure 5: Slapper Detonator Test, using customised title format.

Title : n43 Primers Stressed
Date : 8/6/90 **OIC : L.Redman**

A. Description of Explosive Material Used

TYPE : CAPS

COMPOSITION : CC

ADD. DATA :

B. Test Conditions

SET-UP :

TYPE OF DEVICE USED :

ADD. INFORMATION :

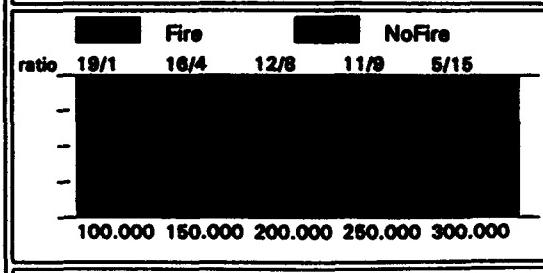
Level	x	Fire	NoFire	Total	% Fire	Emp. Probit	Prov. Probit	Exp. Probit
100.000	2.000	1	19	20	5.000	3.355	3.335	3.355
150.000	2.176	4	16	20	20.000	4.159	4.128	4.159
200.000	2.301	8	12	20	40.000	4.747	4.690	4.747
250.000	2.398	9	11	20	45.000	4.875	5.127	4.873
300.000	2.477	15	5	20	75.000	5.674	5.483	5.665

Statistical Results :

%	Mx	Sx (LOG)	x95%
99.999	2074.881	0.223	892.163
99.990	1569.799	0.196	746.006
99.900	1138.251	0.166	606.747
99.000	770.207	0.130	471.509
95.000	543.533	0.097	375.707
50.000	234.323	0.033	206.501
10.000	121.657	0.060	97.010
1.000	71.289	0.107	47.569
0.100	48.238	0.143	28.065
0.010	34.976	0.173	18.152
0.001	26.463	0.199	12.430

Mean & StdDev. Results for x

Mean,m	: 2.370
Sm	: 0.033
sd	: 0.222
Ss	: 0.049



FileName : fig6.pro

Figure 6: Conducting Composition Cap Sensitivity Test, using customised title format.

Title : N43 Caps in Primers Unstressed
Date : 20/11/91 OIC : L.Redman

A. Description of Explosive Material Used

TYPE : CAPS

COMPOSITION : CC

ADD. DATA :

B. Test Conditions

SET-UP :

TYPE OF DEVICE USED : Caps

ADD. INFORMATION :

Level	Fire	NoFire	Total	Pi(NoFire)	Ki	Ki Pi
100.000	0	20	20	1.000	1	1.000
150.000	1	19	20	0.950	3	2.850
200.000	3	17	20	0.850	5	4.250
250.000	10	10	20	0.500	7	3.500
300.000	14	6	20	0.300	9	2.700
350.000	18	2	20	0.100	11	1.100
400.000	18	2	20	0.100	13	1.300
450.000	20	0	20	0.000	15	0.000

Statistical Results :

Sum(KiPi) : 16.700

Sum(Pi) : 3.800

Mean,m : 315.000

sd : 75.166

sd' : 1.503

FileName : fig7.amc

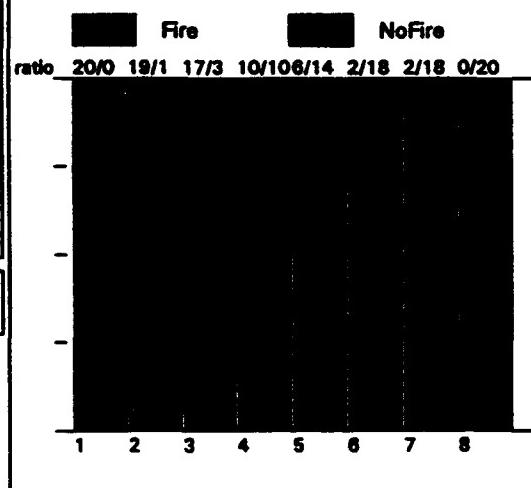


Figure 7: Conducting Composition Cap Sensitivity Test, using customised title format.

Appendix V: Experimental Test Set-up

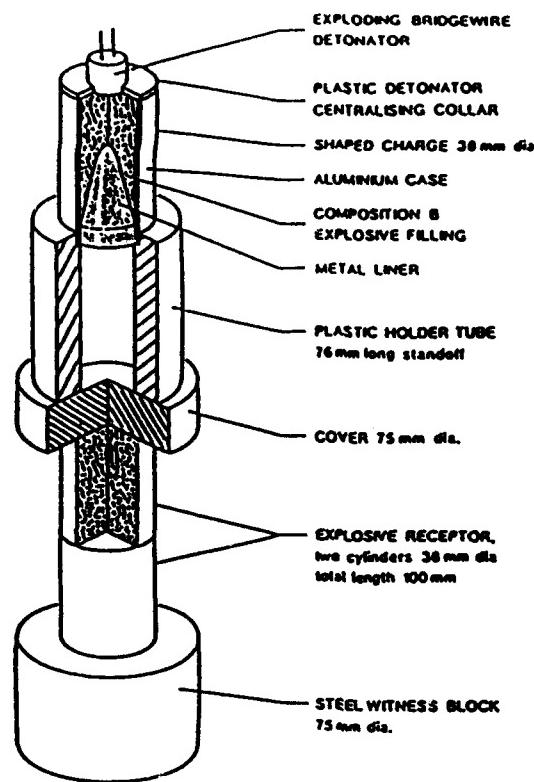


Figure 1: Assembly for the MRL Jet Sensitivity Test on covered Explosives

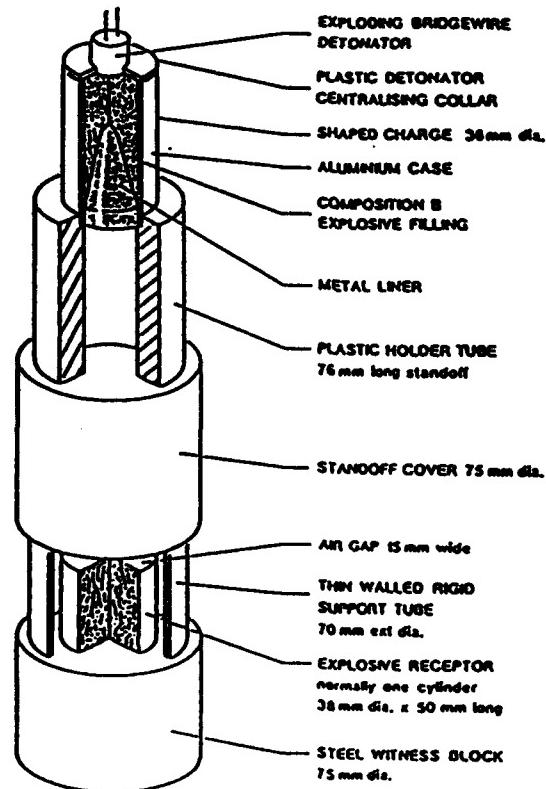


Figure 2: Sectioned view of the MRL Jet Sensitivity Test for bare Explosives.

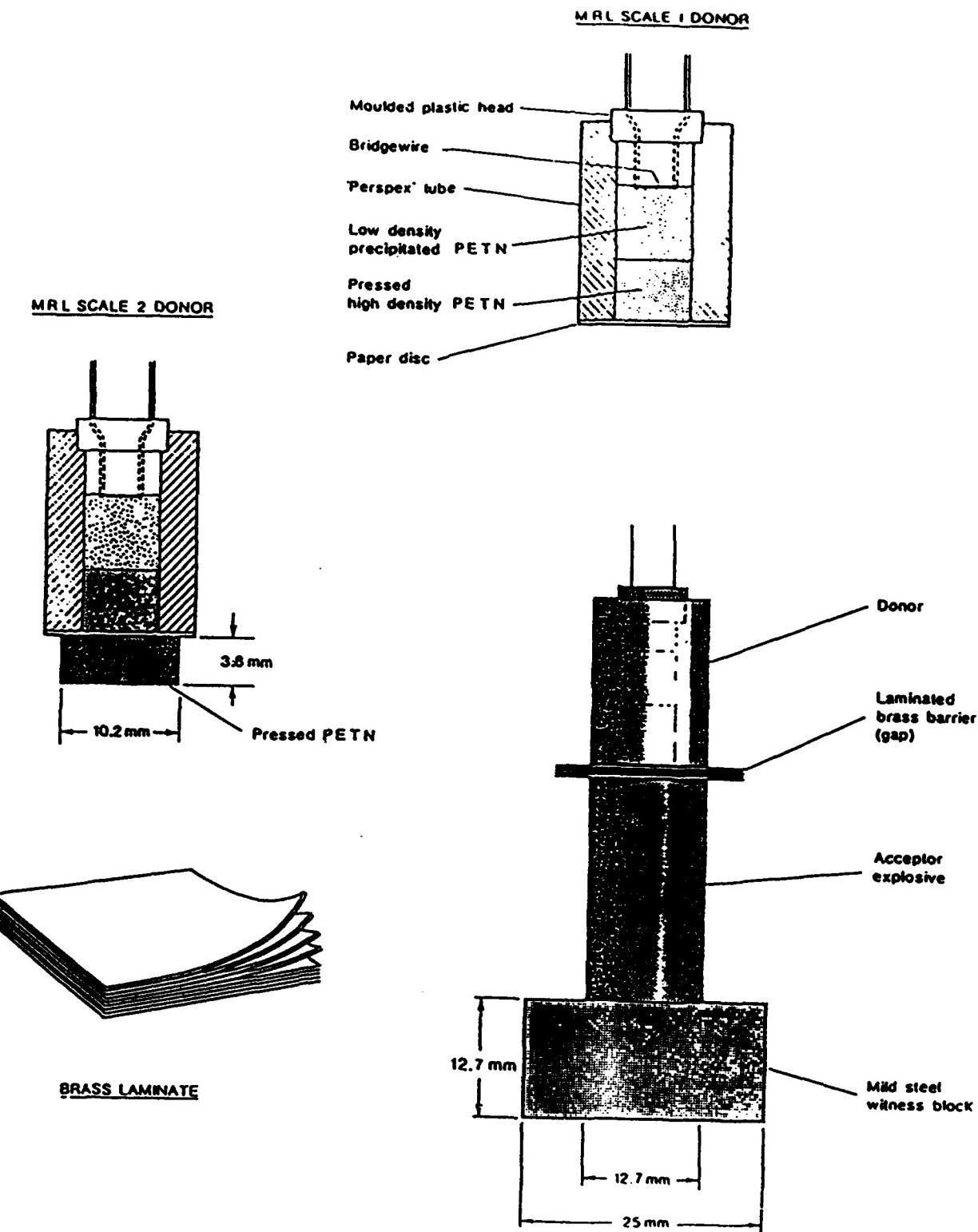


Figure 3: The MRL Small Scale Gap Test (SSGT) assembly.

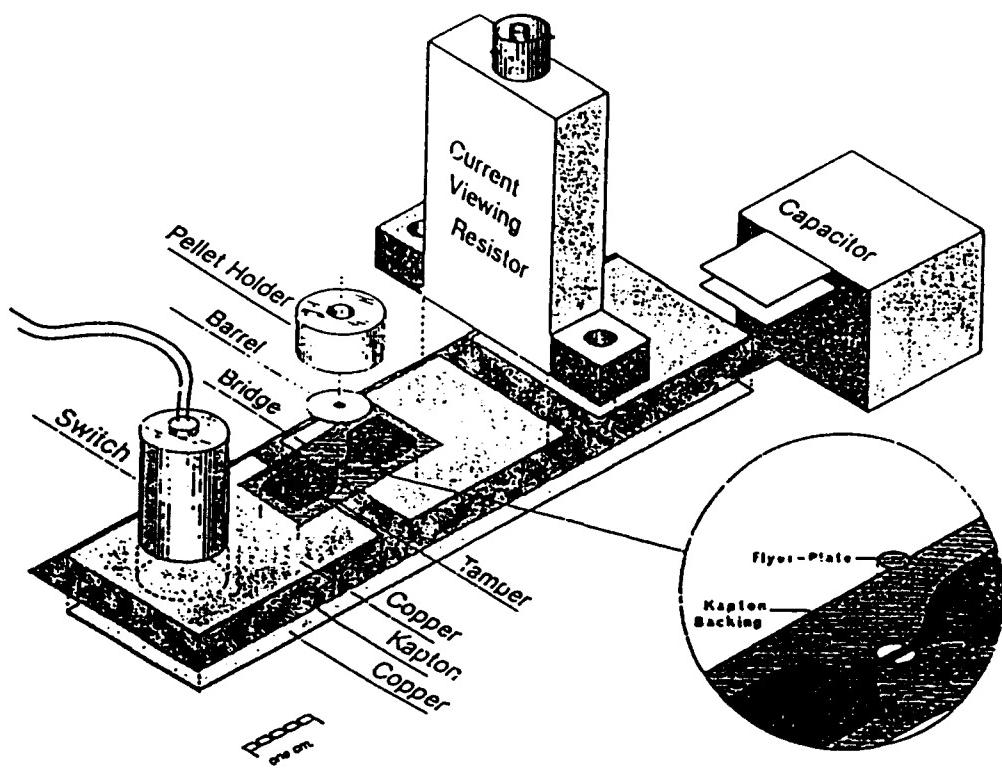


Figure 4: Slapper Detonator Assembly.

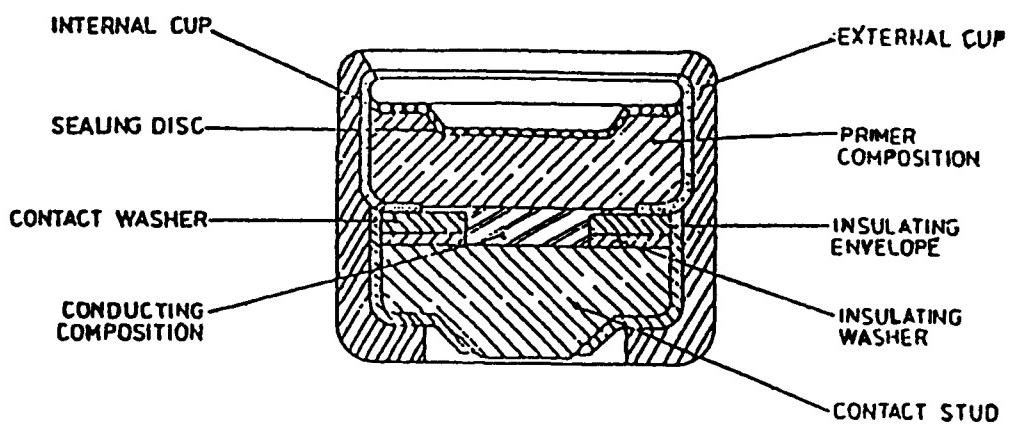


Figure 5: A typical Conducting Composition Cap.

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Cap Sensitivity Test

ABSTRACT

The report describes a user-friendly software package for the analysis and presentation of results from explosive destructive testing. The analysis covers the Bruceton, Probit and Army Materiel Command Regulation (AMCR) statistical methods. The program is illustrated by its application to several small scale tests for the assessment of explosive sensitivity to various stimuli. They are the Gap test, Jet Sensitivity test, Slapper Detonator test and Cap Sensitivity test.

The report includes an overview of the basis of the mathematical equations used in the evaluation of the statistical data, and the menu commands in the computer model are described.

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Explosive Testing**

C. Lam

(MRL-TR-93-42)

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